Laser Peening Effects on Friction Stir Welding

Omar Hatamleh
Johnson Space Center

Contents

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- Residual Stress
- Mechanical Properties
- Fatigue Properties

Background

FSW

Friction Stir Welding (FSW) is a welding technique that uses frictional heating combined with forging pressure to produce high strength bonds.

Applicable

Attractive for aerospace applications

- Can result in considerable cost and weight savings, by reducing riveted/fastened joints, and part count
- Can weld metals that are difficult to weld with conventional methods
  - Space shuttle

RS

Although residual stresses in FSW are generally lower when compared to conventional fusion welds, recent work has shown that significant tensile residual stresses can be present in the weld after fabrication

Effects

Residual tensile stresses in the weld can lead to:

- Faster crack initiation
- Faster crack propagation
- Could also result in stress corrosion cracking (SCC)

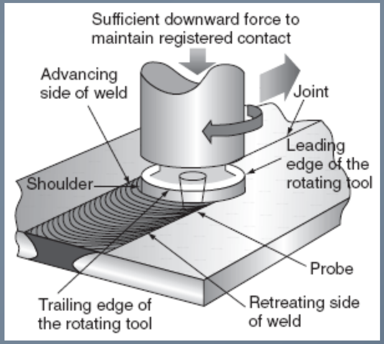
Therefore, laser shock peening was investigated as a means of moderating the tensile residual stresses produced during welding

Background

Friction Stir Welding

Nugget or the stirred zone
- The grain structure usually fine and equiaxed
  - Recrystalization from the high temperatures
  - Extensive plastic deformation

Thermo-mechanical affected zone (TMAZ)
- Lesser degree of deformation and lower temperatures
- Recrystallization does not take place
- The grain structure in elongated, with some considerable distortions



Heat affected zone (HAZ)
- Unaffected by mechanical effects, and is only affected by the friction heat

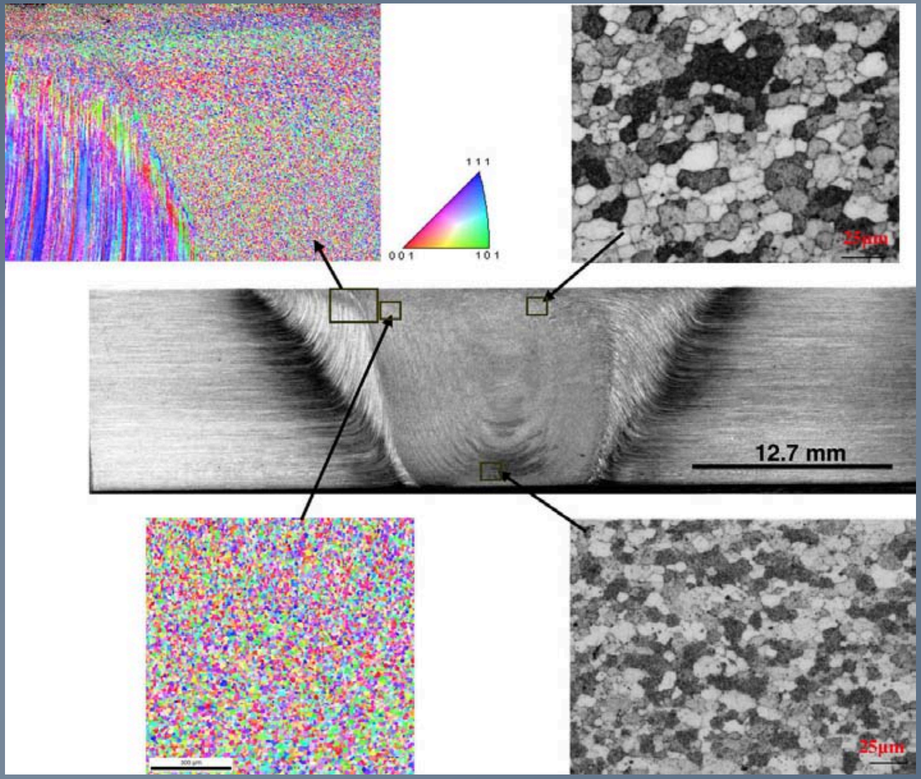
Use of FSW is expanding and is resulting in welded joints being used in critical load bearing structures

Welding Process

The alloy selected was a 1.25 cm thick 2195-T8 aluminum lithium alloy.
Possess many superior properties and is well suited for many aerospace applications due to its low density, high strength, and corrosion resistance.
For the welding process, a rotational speed of 300 RPM in the counter-clockwise direction and a translation speed of 15 cm/min were used.
The dimensions of the FSW panels were 91 cm x 30 cm x 1.25 cm.
To verify the integrity of the weld, several bending tests were performed.
The FSW specimens were inspected visually afterward with no crack indications revealed.

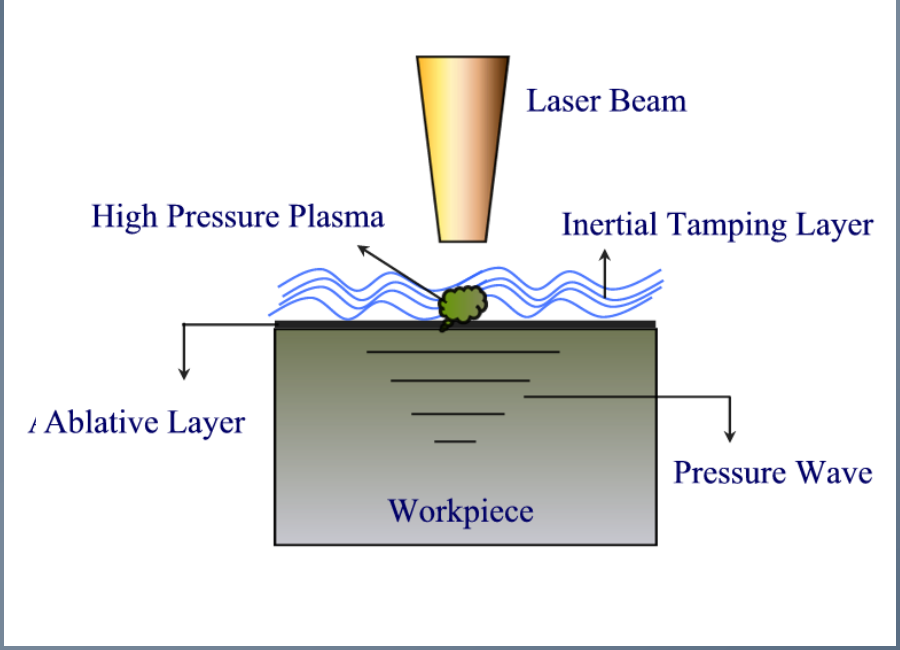
Background

Microstructure



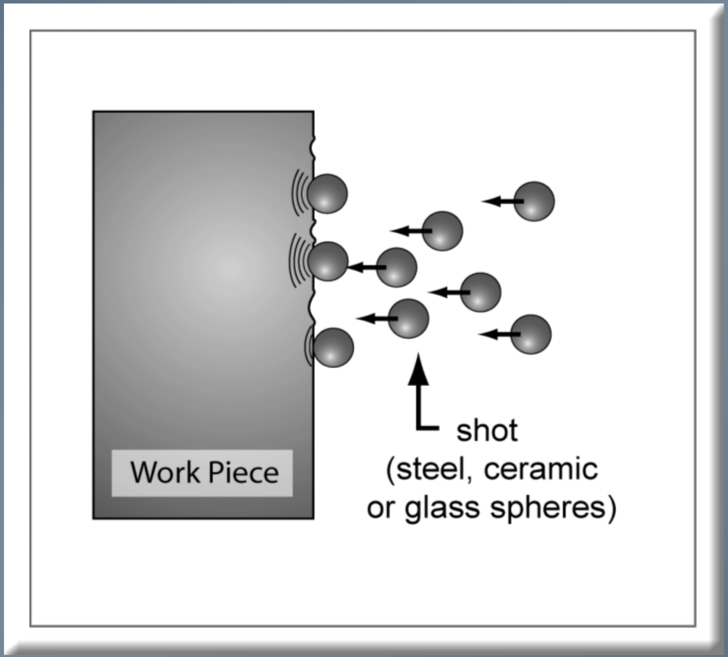
Background

Laser Peening



Background

Shot Peening



Peening Process

FSW Samples

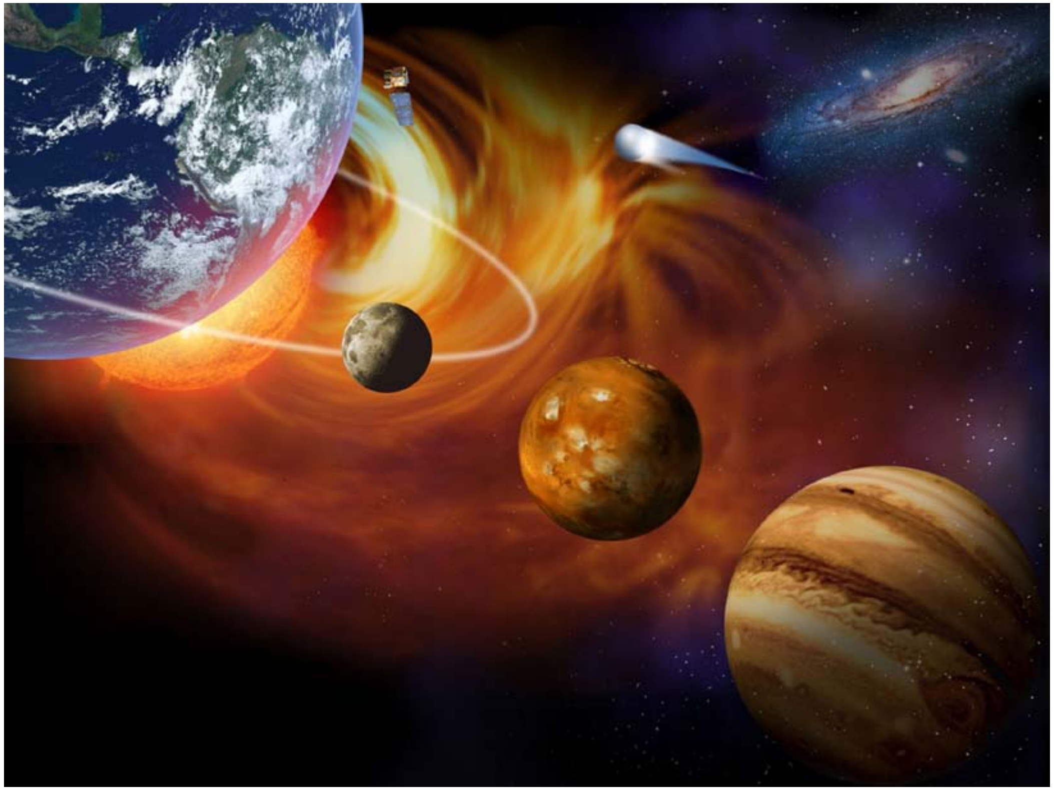
Laser Peening

- 1 mm thick laminar tamping layer
- Samples covered using a 0.22 mm thick aluminum tape
- Applied using a square laser spot
- Laser power density of 5 GW/cm^2
- 18 ns in duration
- Spots were overlapped 3%
- Applied at a frequency of 2.7 Hz
- Using a 1 micrometer wavelength
- Both faces of samples were peened

Shot Peening

- 0.59 mm glass beads
- Almen intensity of 0.008-0.012
- Both faces of samples were peened

Residual Stresses



Residual Stresses

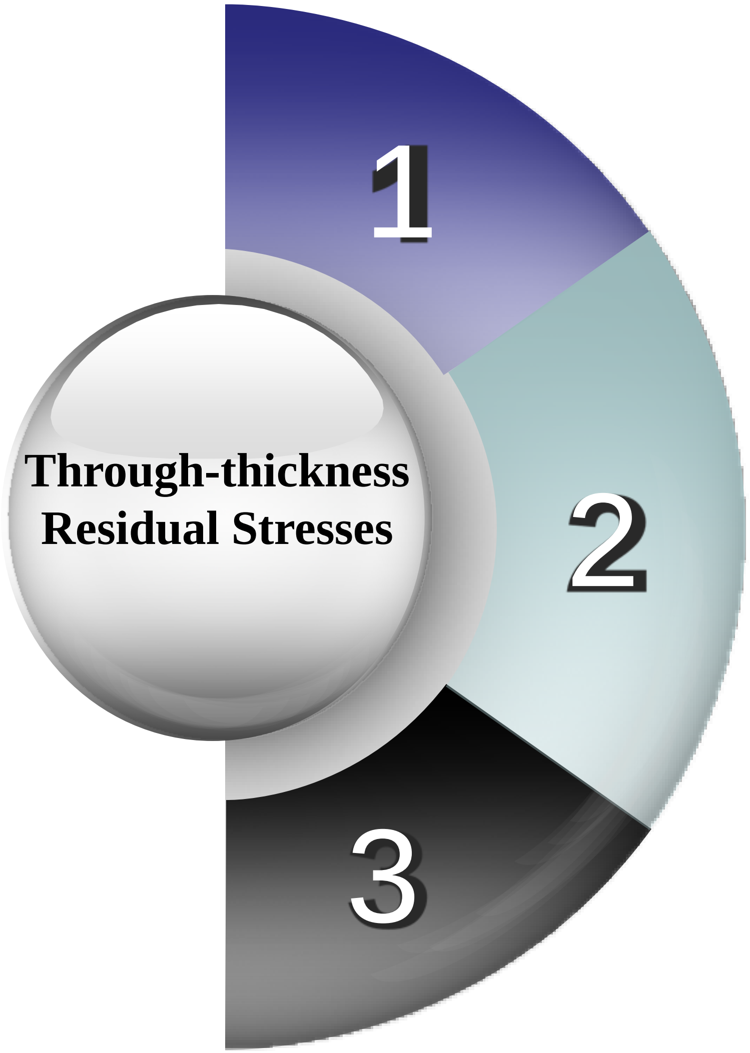
XRD

Surface Residual Stresses
Determined by the x-ray diffraction technique

Contour

Through Thickness Residual Stresses
Determined by the contour method

Contour Method



1. Sectioning the Sample

- Sample is fixed to a rigid backing plate
- Sample is cut along the measurement plane with an EDM wire

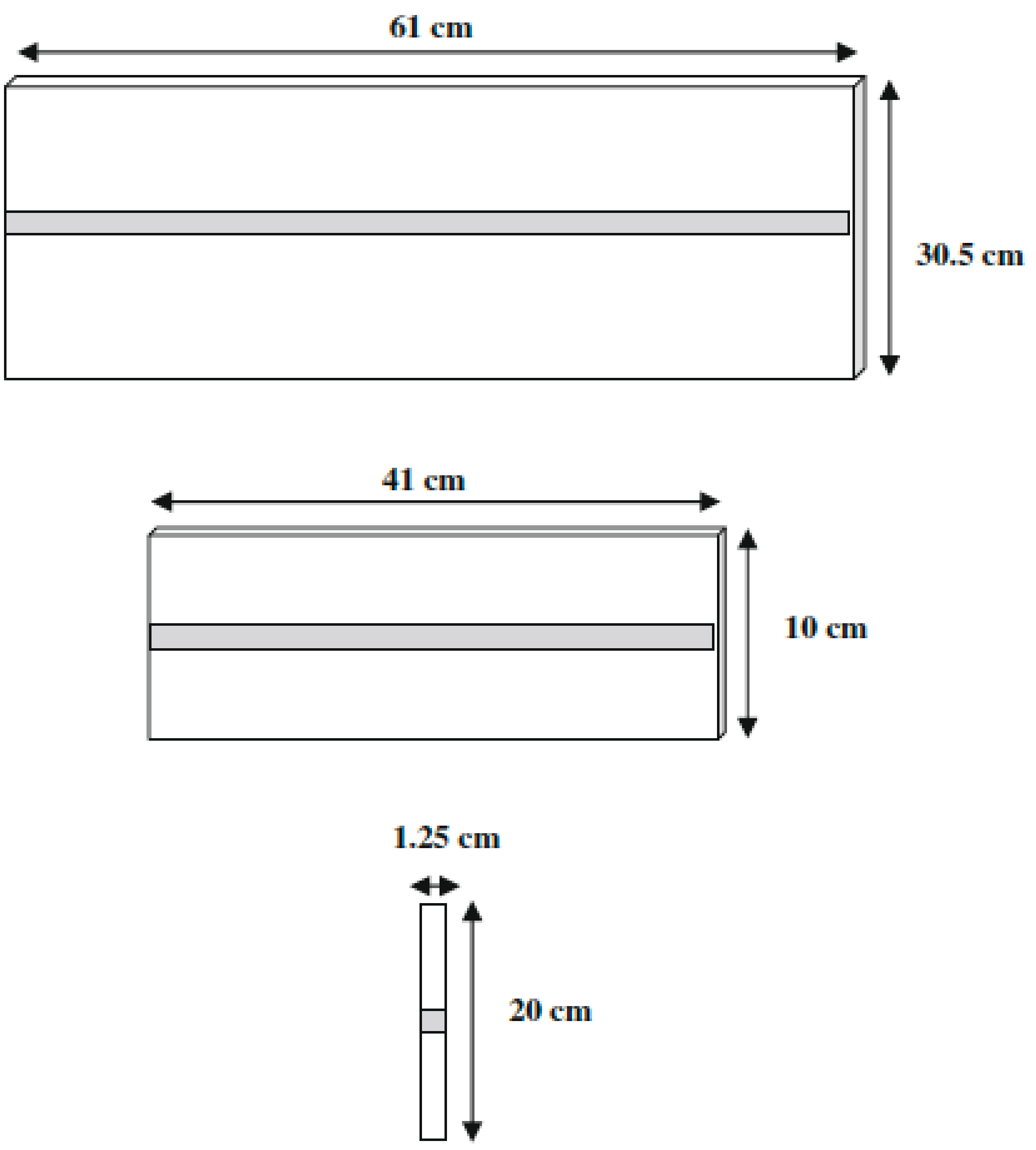
2. Measuring Deformation

- After sectioning a deformed surface shape is produced
    - Resulting from the relaxed residual stresses
- The displacement is measured on both sectioned surfaces using a coordinate measuring machine (CMM)

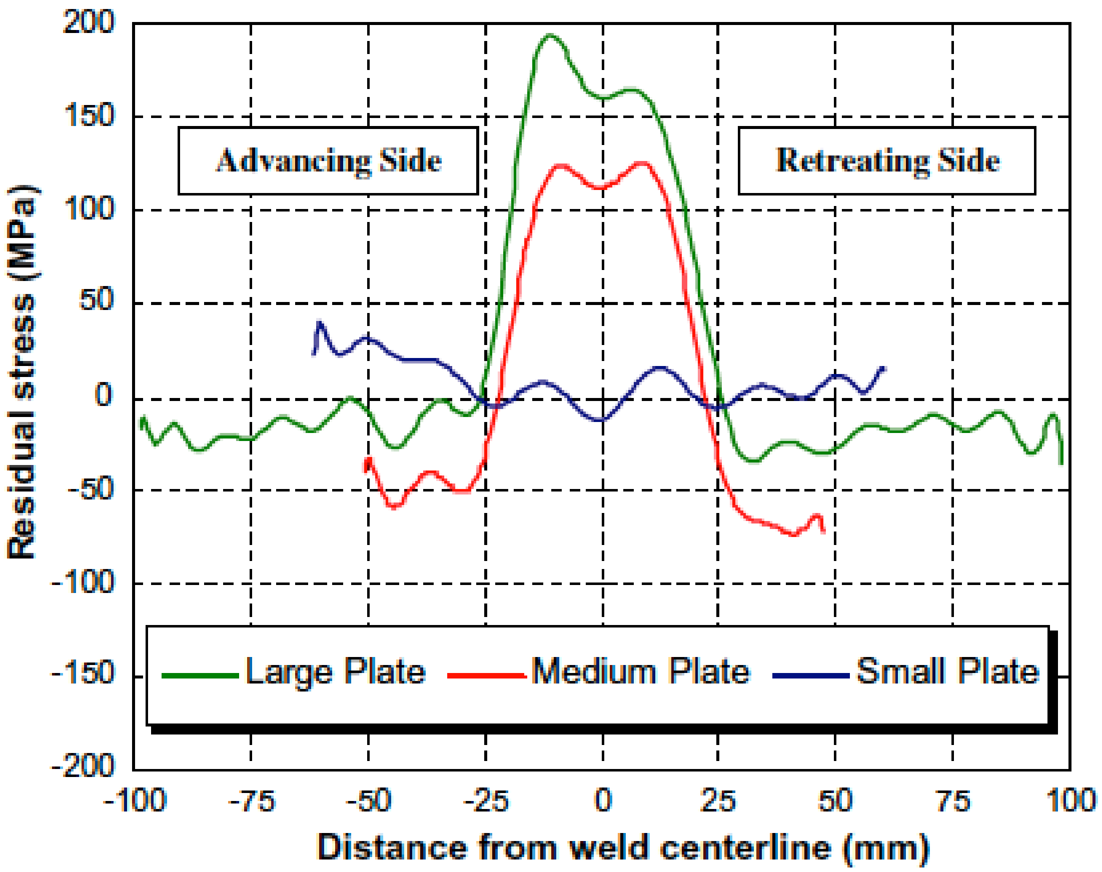
3. Estimating the Residual Stresses

- The displacements from both cutting surfaces is averaged
- The noise in the measurements is filtered
- The original residual stresses are calculated from the measured contour using a finite element model (FEM)

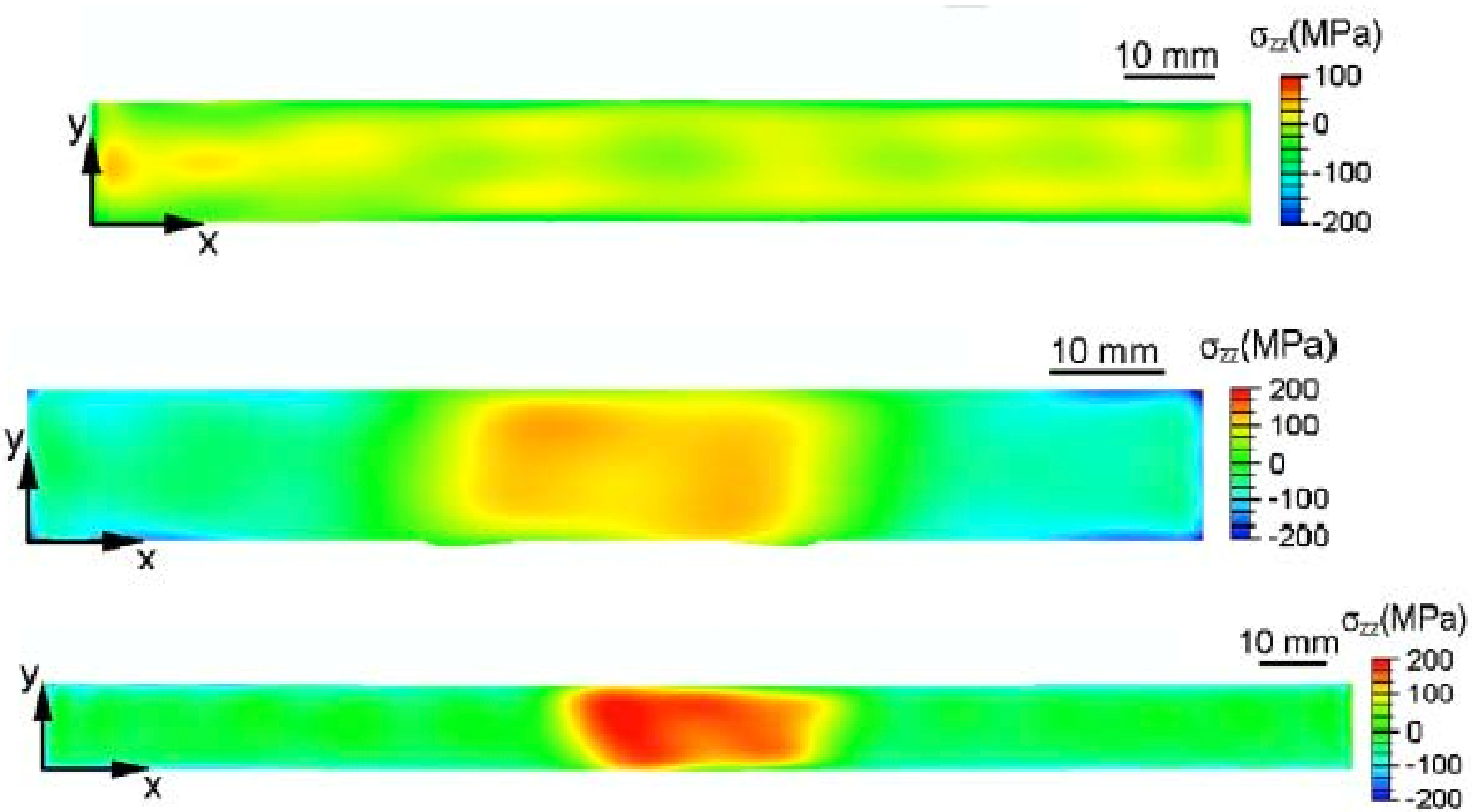
Residual Stress Quantification



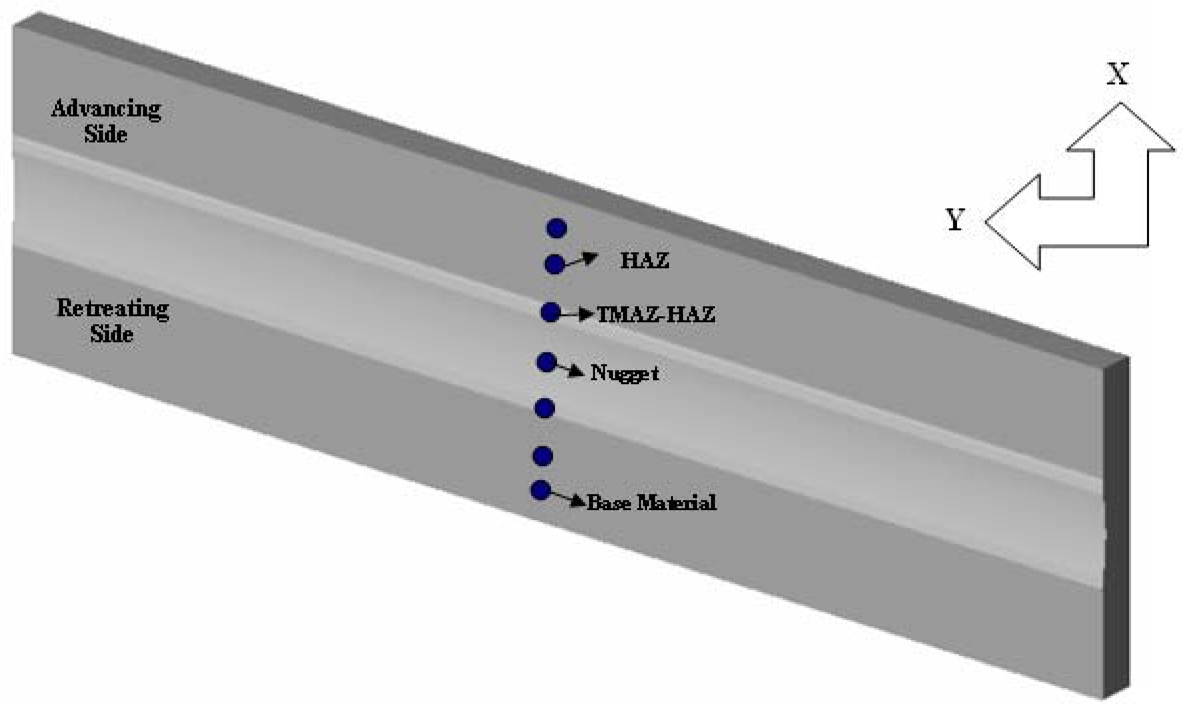
Residual Stress Relaxation



Through Thickness Residual Stress

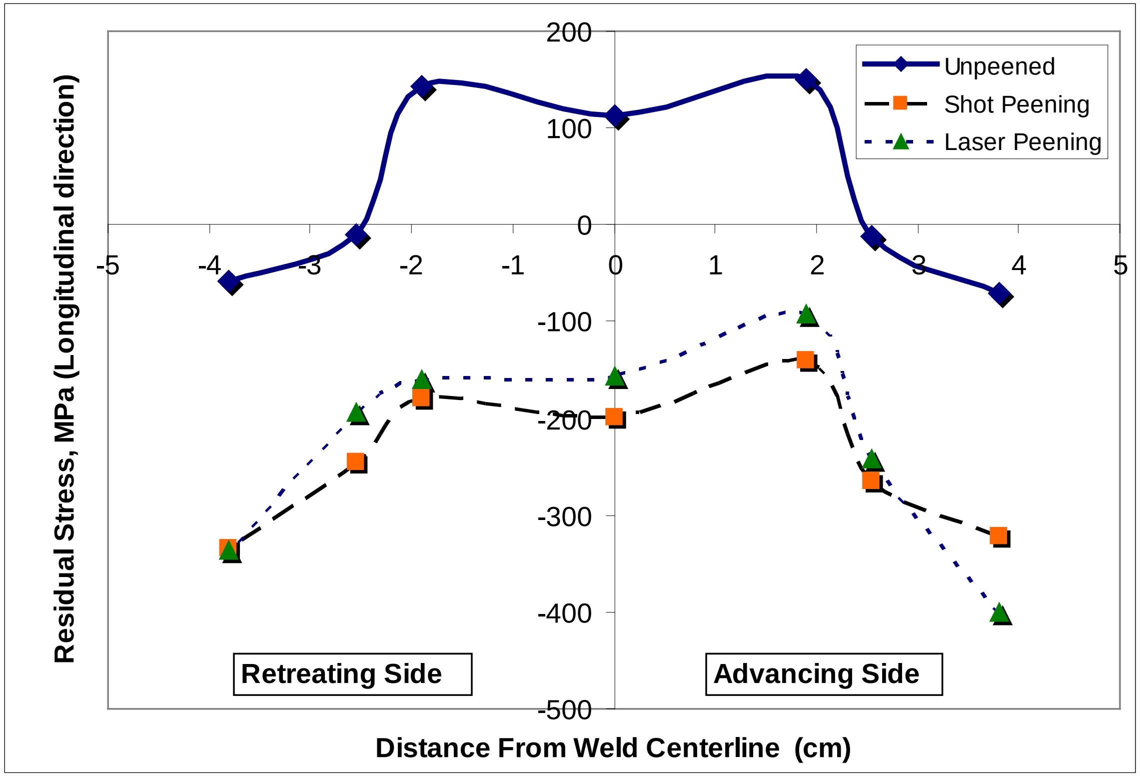


Samples Used in Testing



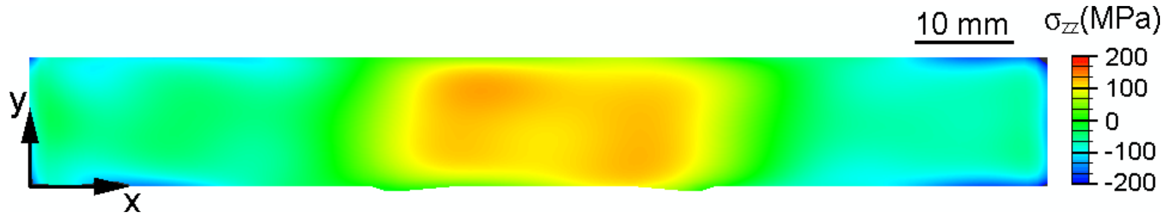
Residual Stress in FSW

Surface residual stresses

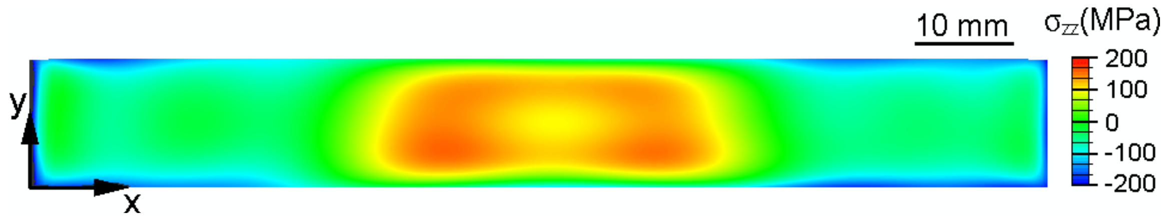


Residual stresses for the various peened FSW specimens

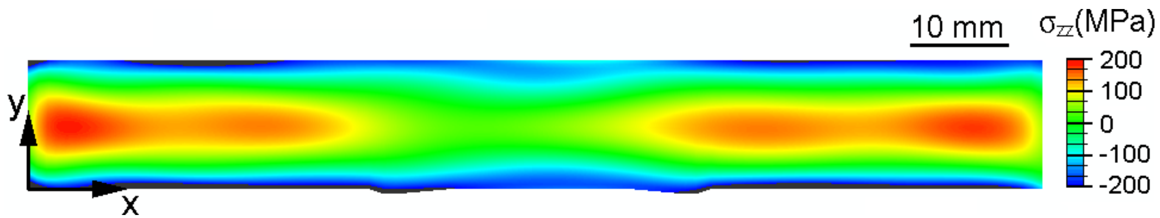
Effects of Laser Peening on Residual Stress in FSW



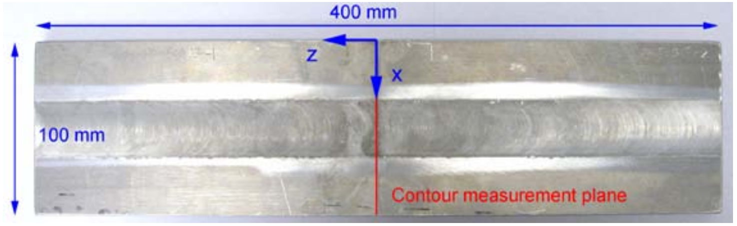
Two-dimensional map of the measured residual stress for the unpeened FSW specimen



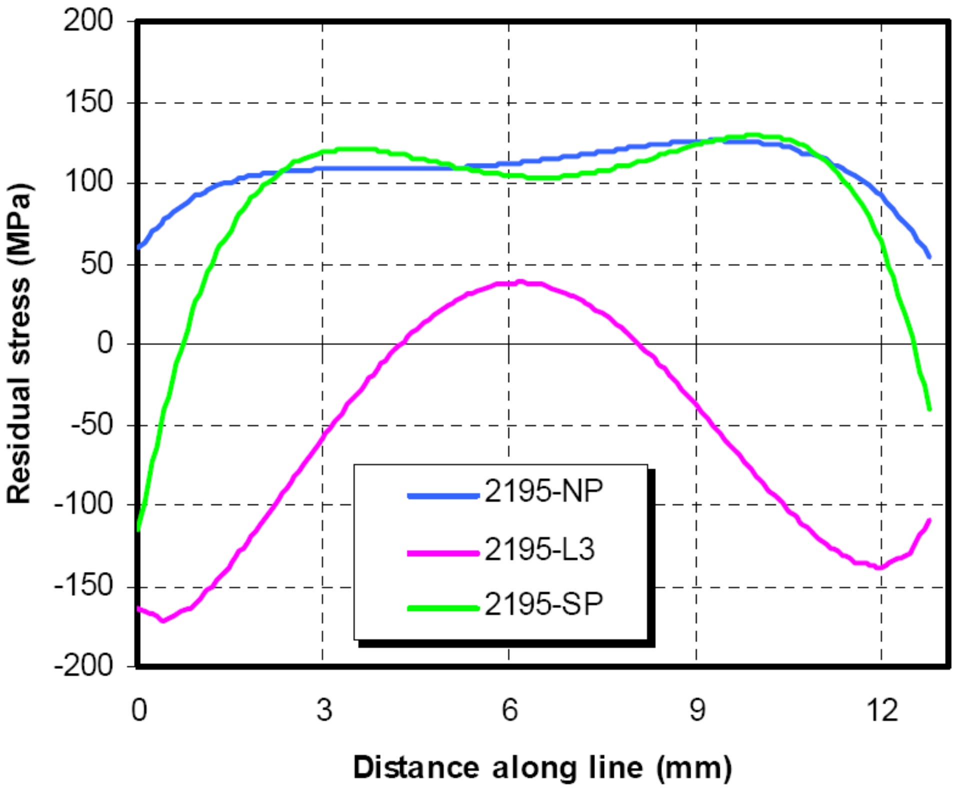
Two-dimensional map of the measured residual stress for the shot peened FSW specimen



Two-dimensional map of the measured residual stress for the laser peened FSW specimen



Through Thickness Residual Stress Measurements



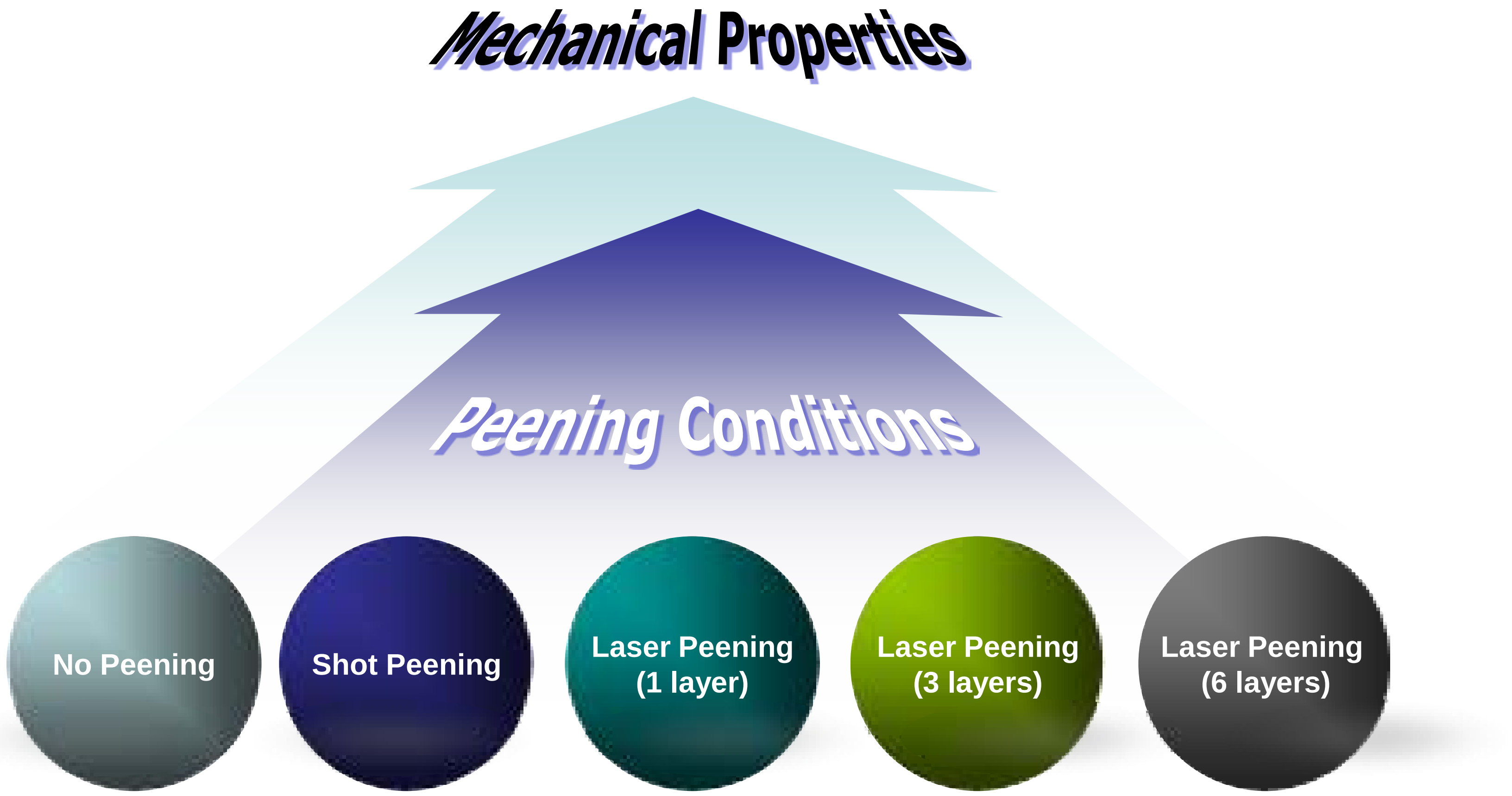
Mechanical Properties

Mechanical Properties

Investigate the effects of peening

- Tensile Properties
- Microhardness
- Surface Effects

Peening Conditions



Testing Methods

Tensile Properties

Conventional Samples

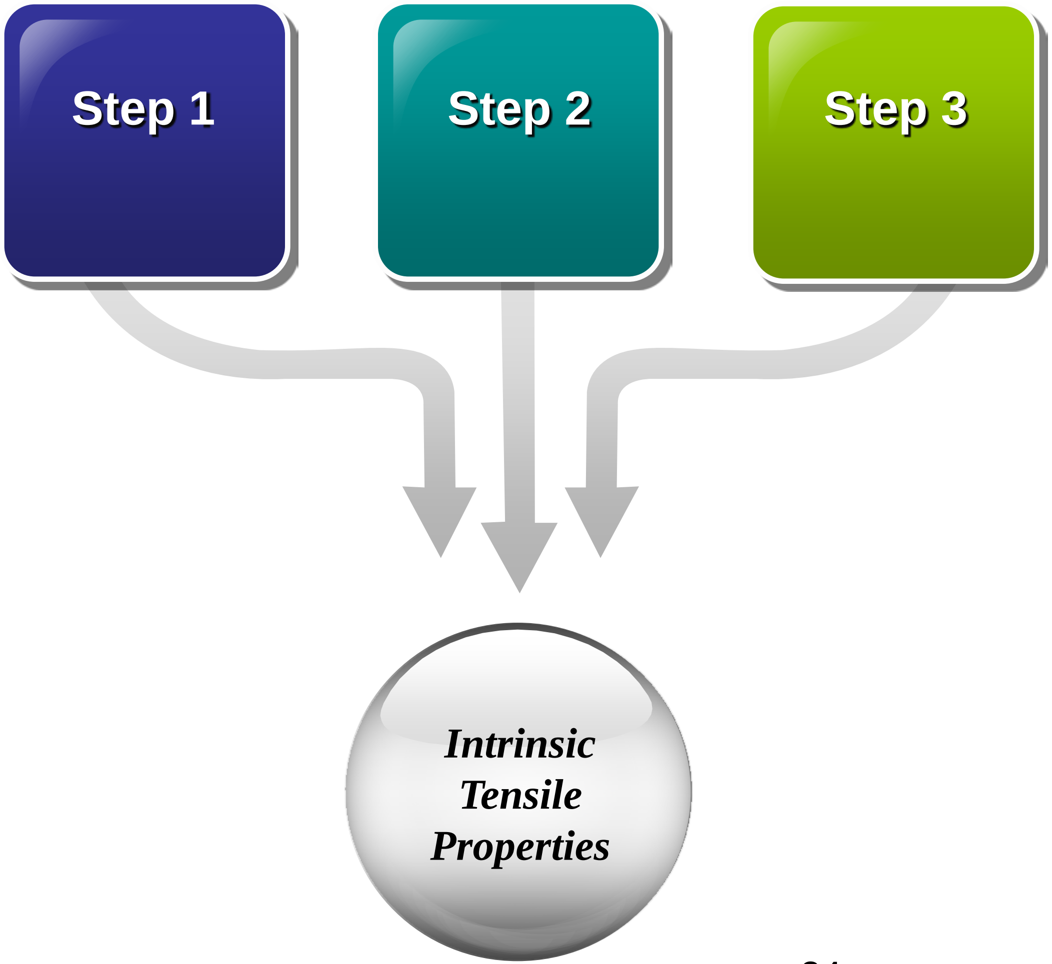
Conventional transverse tensile Testing only provides the overall strain experienced by the sample

Welded Samples

It is necessary to determine local strains and equivalent tensile properties across the weld

Evaluated at different regions of the weld
using an ARAMIS system

Digital Image Correlation



Step 1:

•A random or regular pattern with good contrast is applied to the surface of the test object and is deformed along with the object.

•As the specimen is deformed under load, the deformation is recorded by the cameras and evaluated using digital image processing.

Step 2:

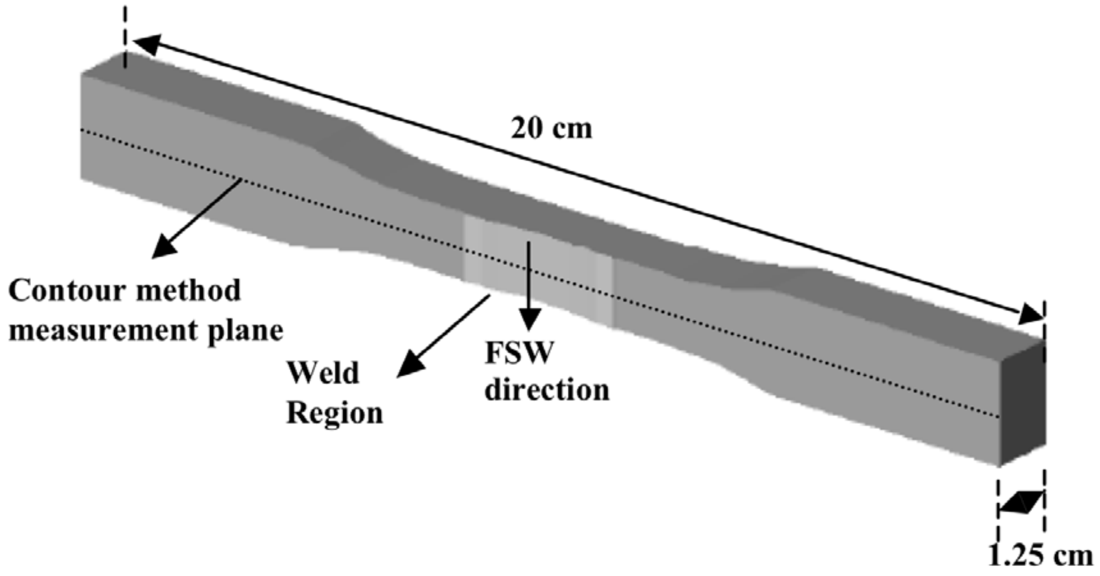
•The initial image processing defines a set of unique correlation areas known as macro-image facets, typically 5-20 pixels across.

Step 3:

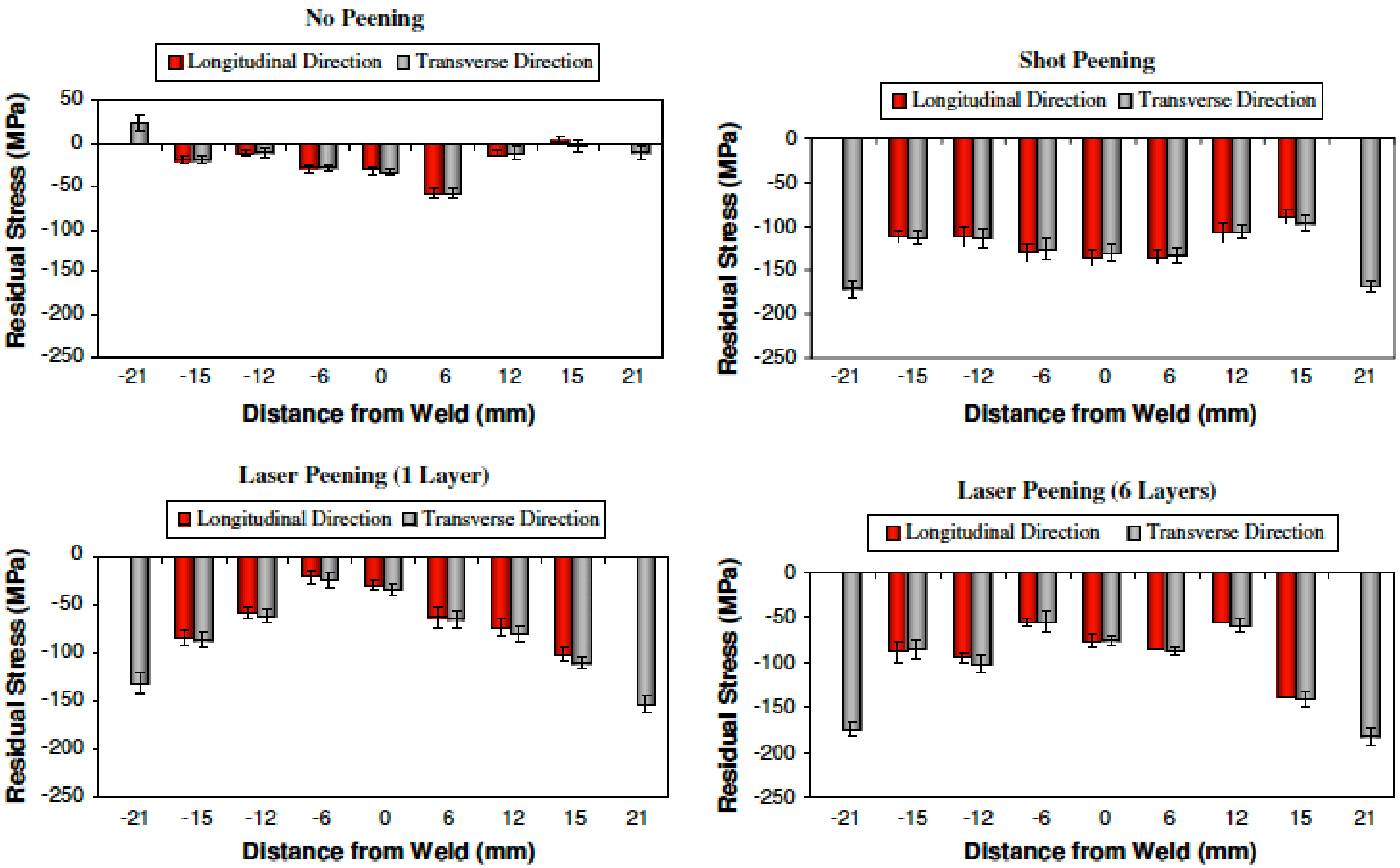
•These facets are then tracked in each successive image with sub-pixel accuracy.

•Strains are calculated at different regions across the weld region.

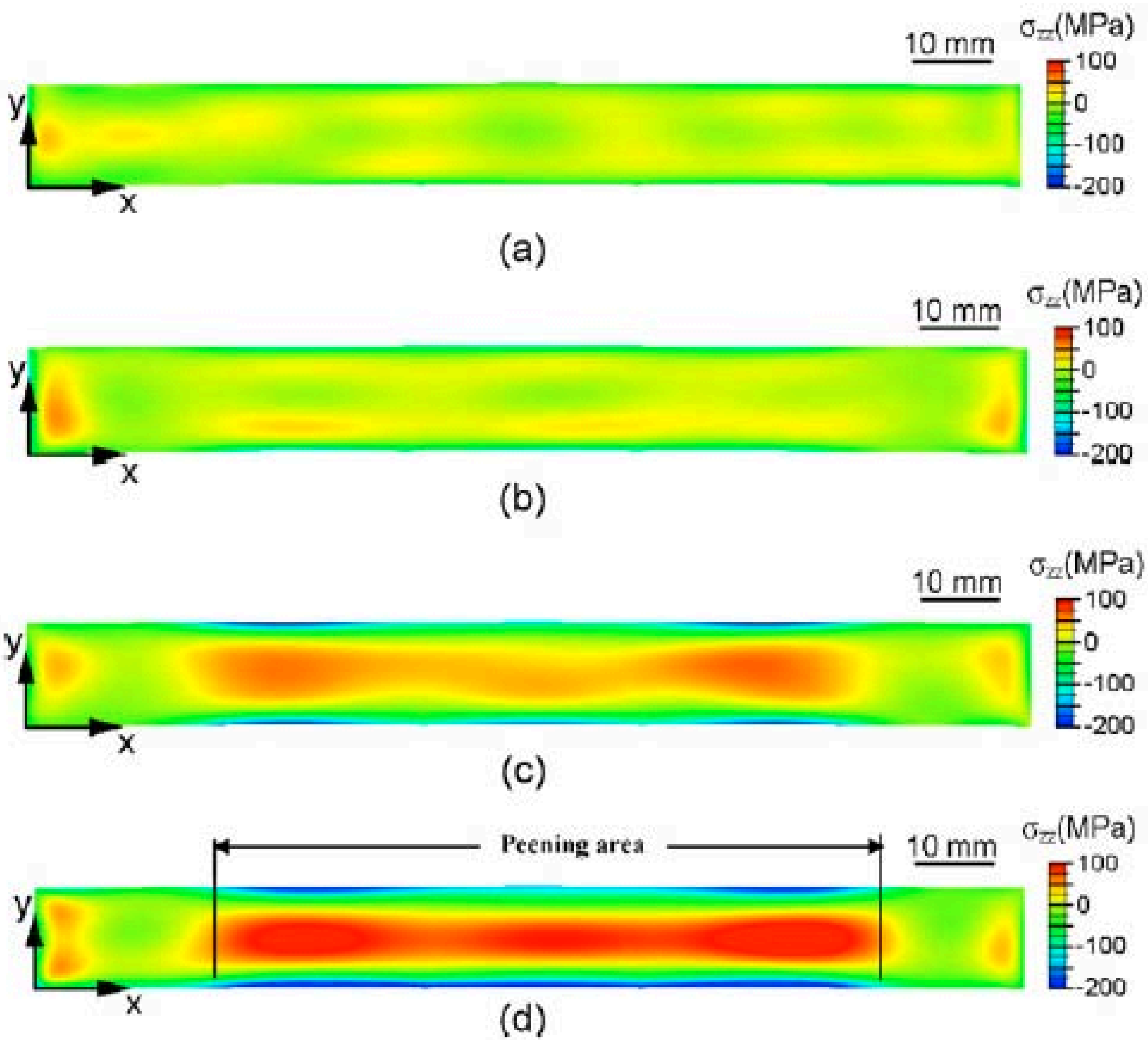
Tensile Testing Samples



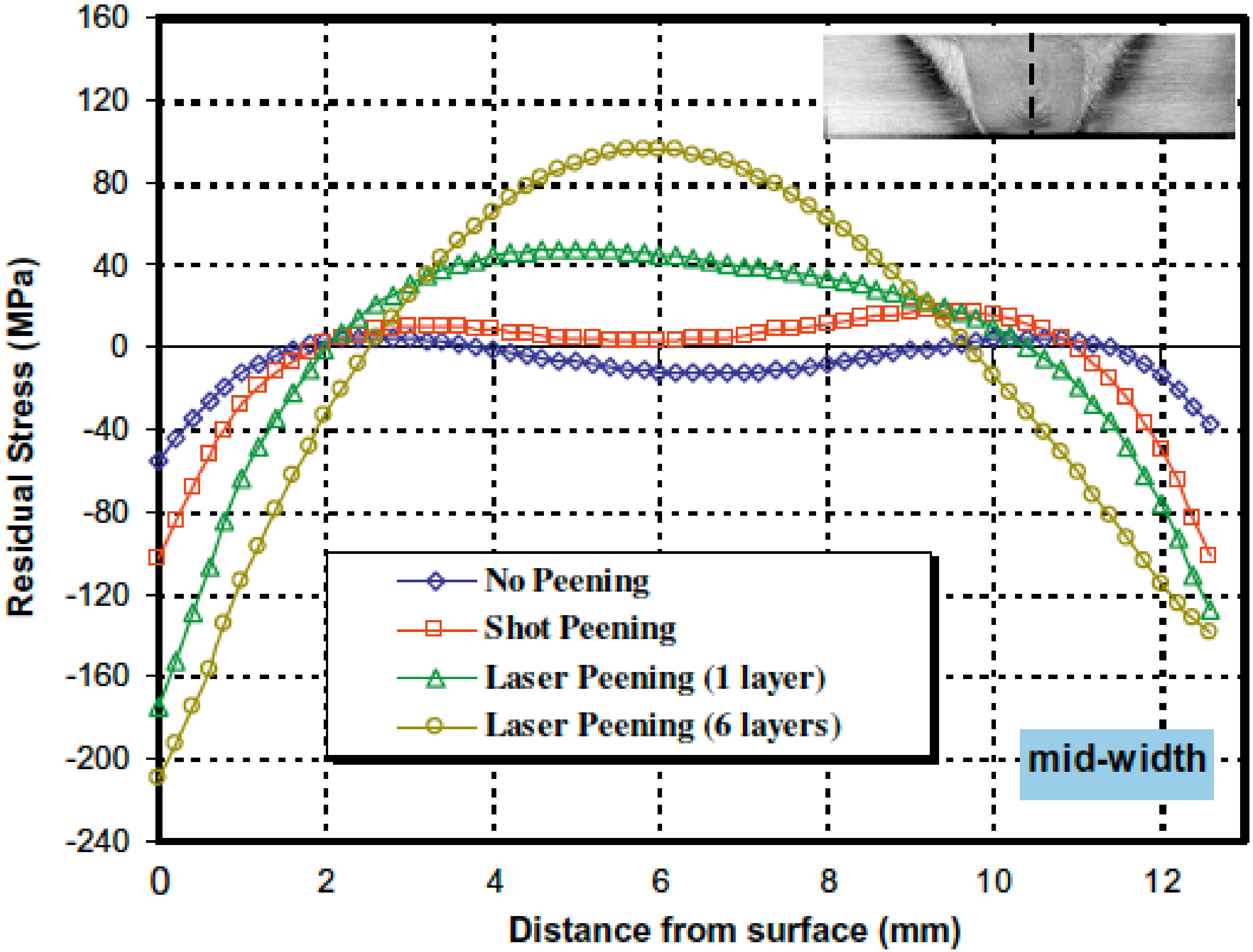
Surface Residual Stress



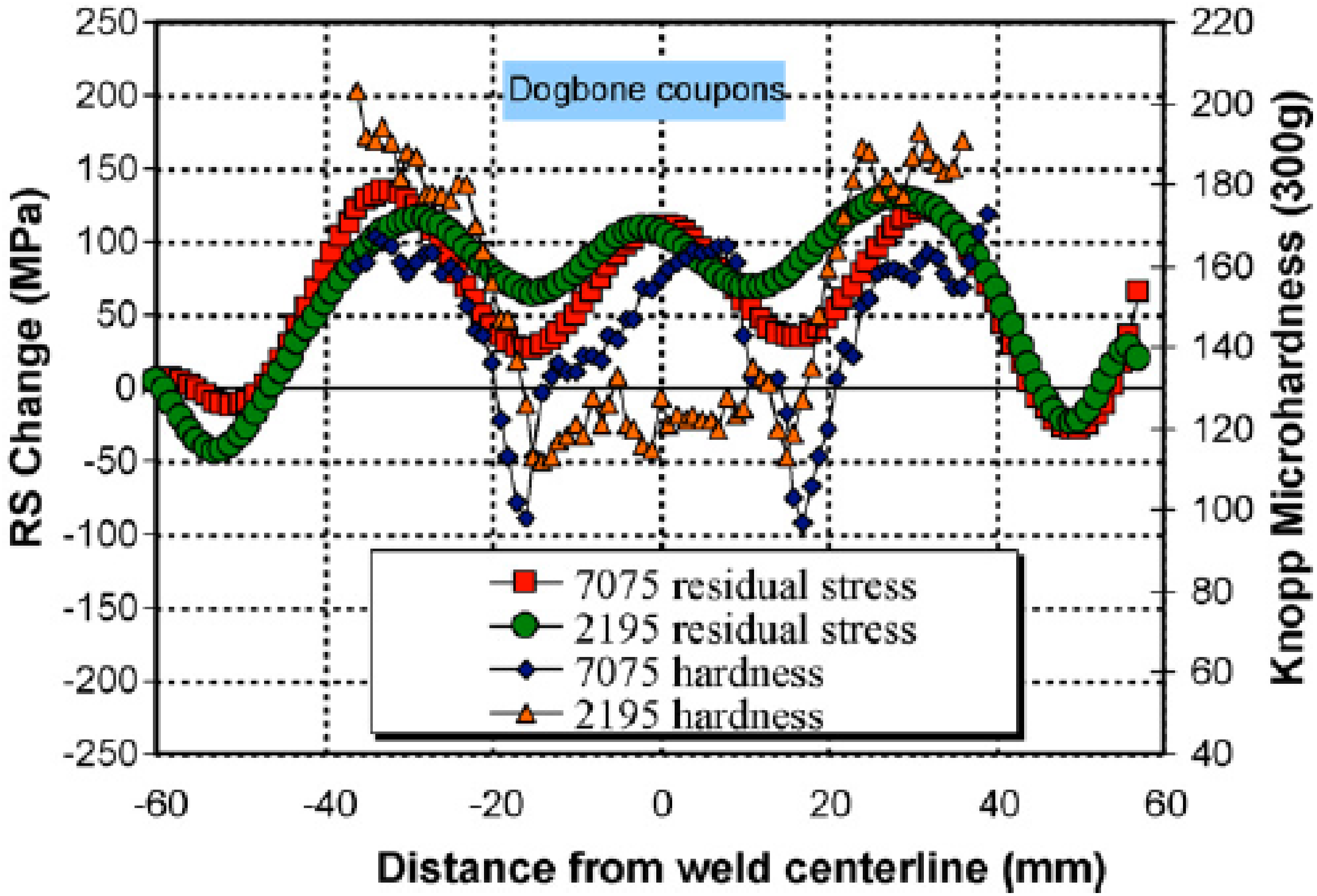
Through Thickness Residual Stress



Through Thickness Residual Stress

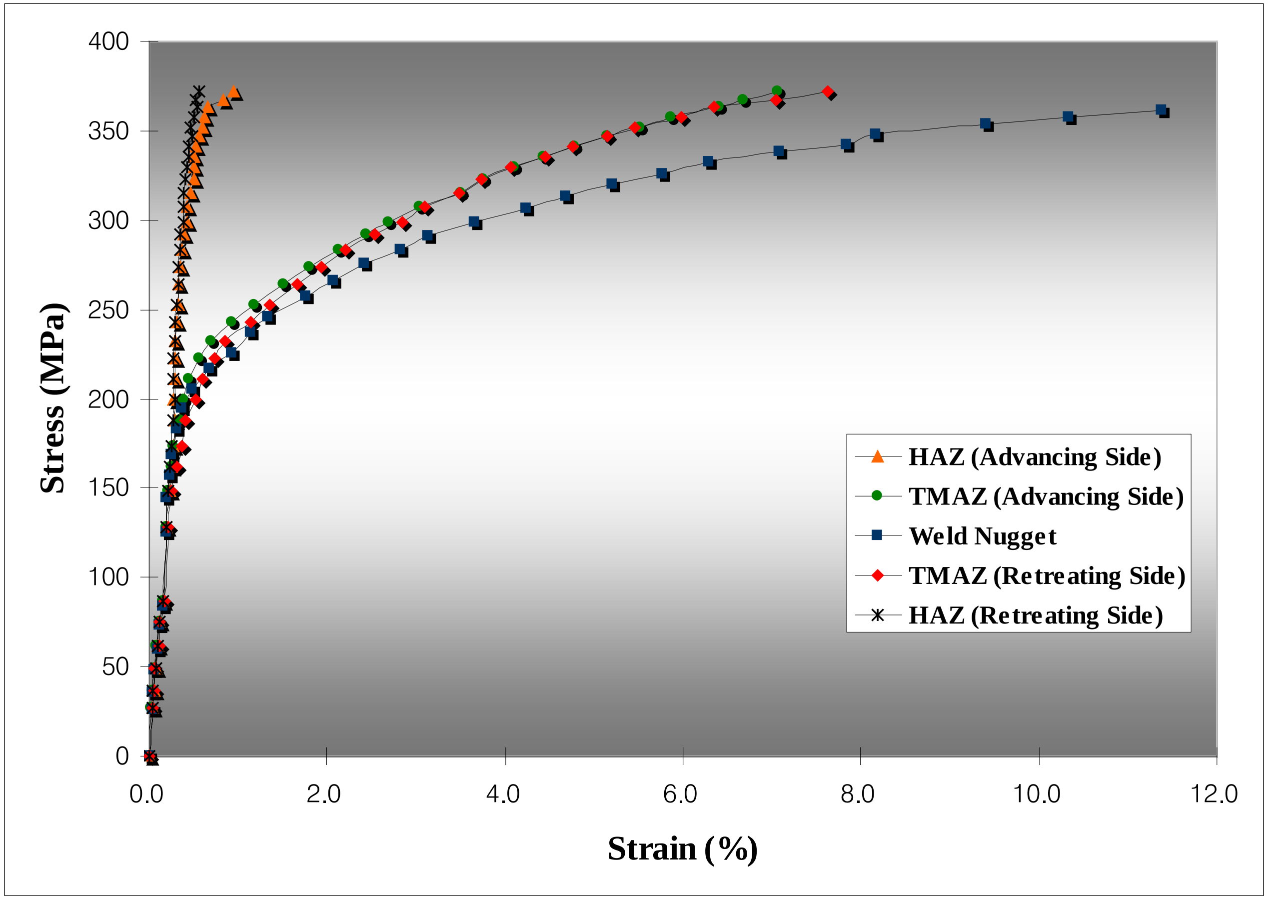


Hardness vs Residual Stress



Tensile Properties for 2195

As welded condition



Tensile properties at different regions of the weld for a FSW 2195 AA

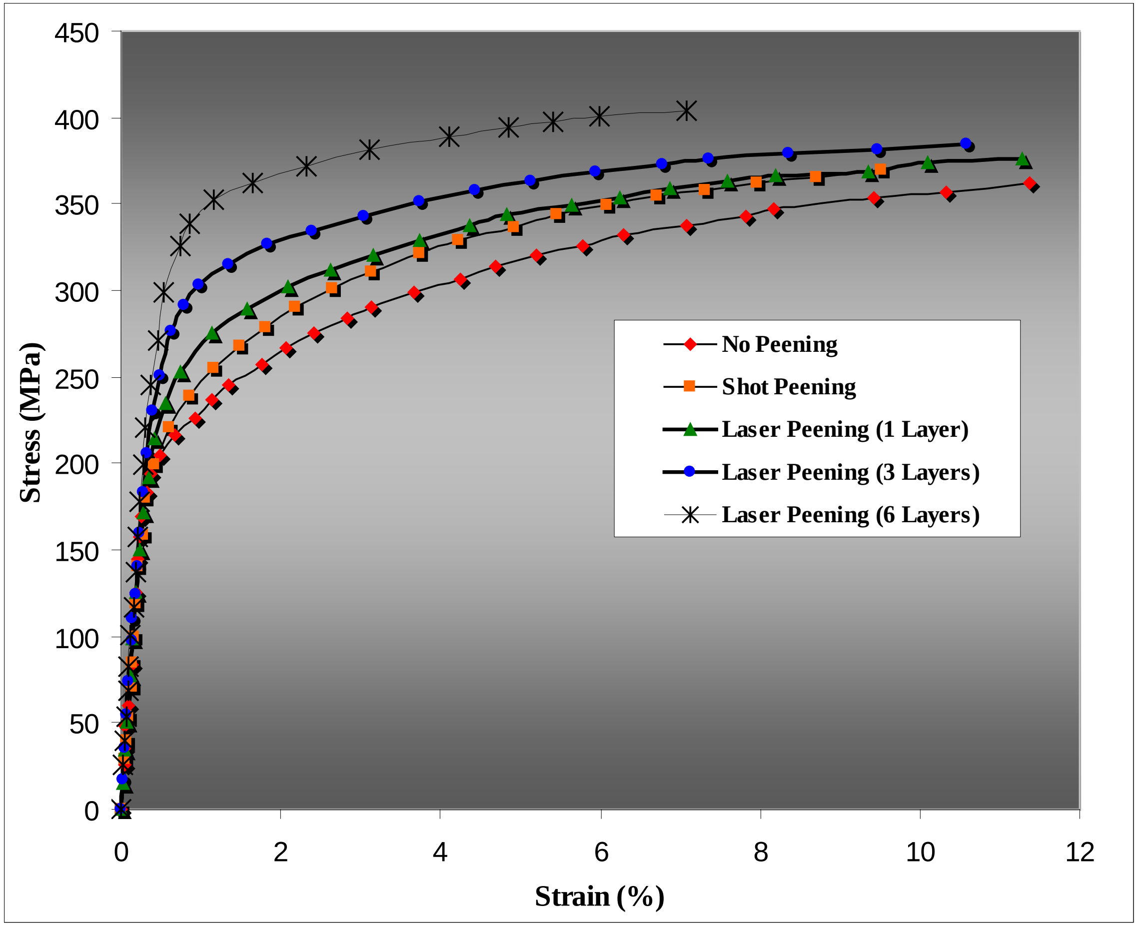
Tensile Properties

Tensile Properties

The weld nugget exhibited the lowest tensile properties when compared to other locations across the weld

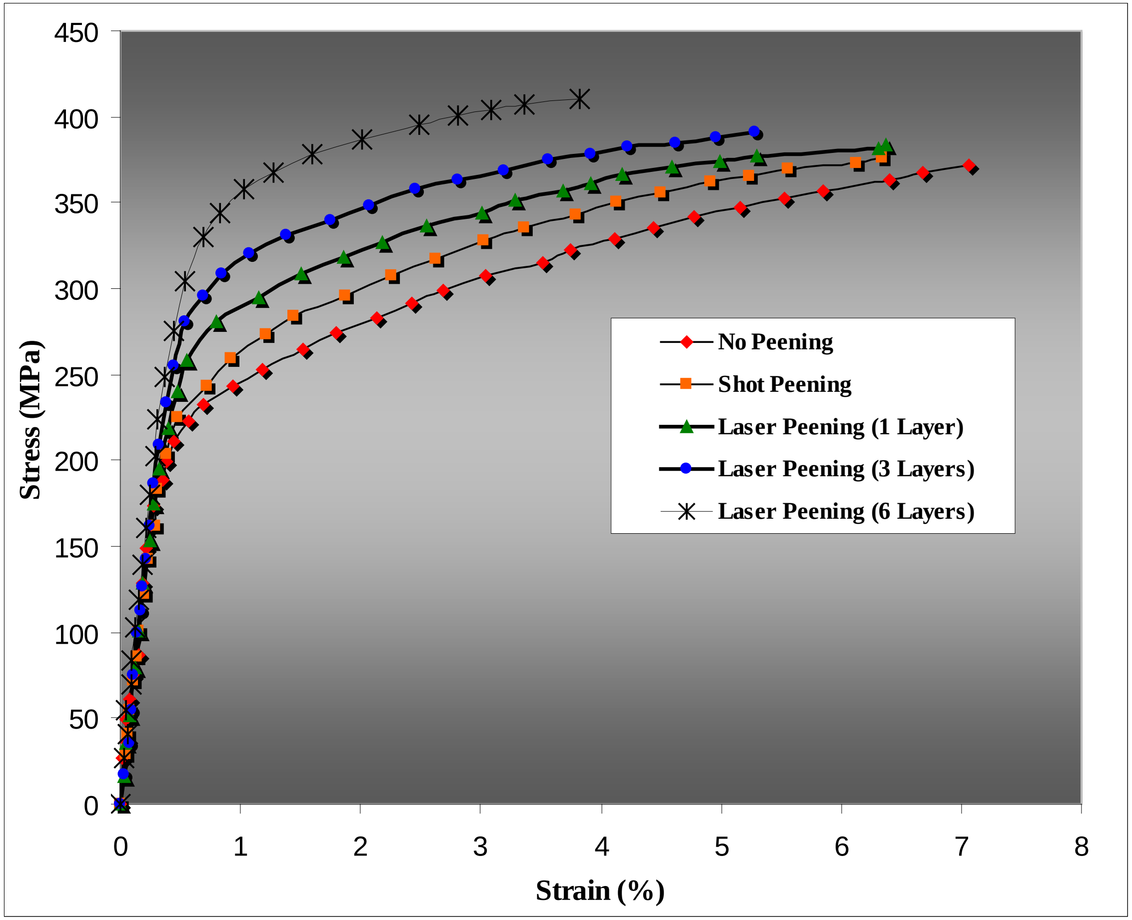
- Strengthening precipitates in 2195 were no longer present in the weld nugget
  - Temperature during joining was above the solution temperature of the hardening precipitates
- This region of the weld will therefore be relatively ineffective in inhibiting dislocation motion
  - The localized strain in the softened area of the weld will result in lower mechanical properties

Tensile Properties at Weld Nugget



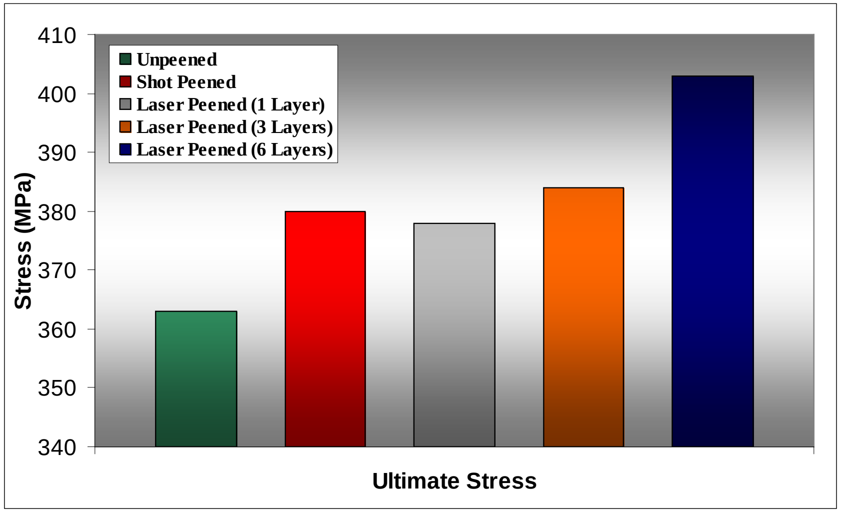
Tensile properties at the weld nugget under different peening conditions

Tensile Properties at TMAZ

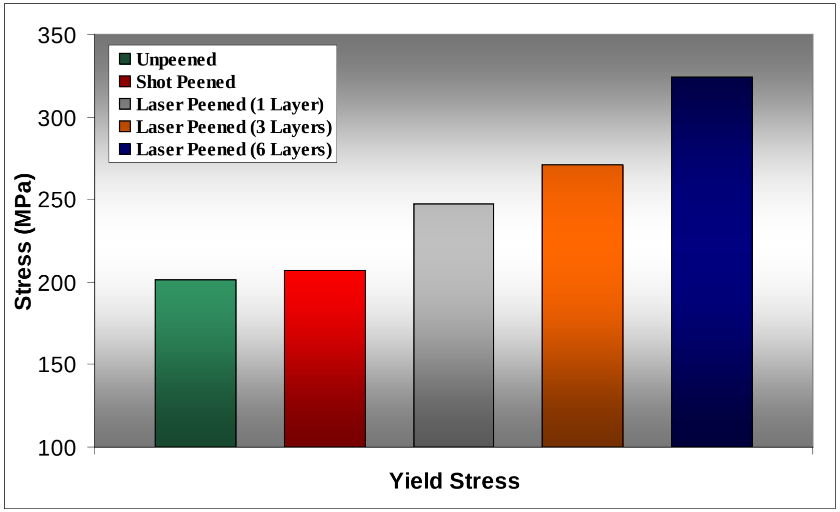


Tensile properties at the TMAZ under different peening conditions

Global Yield and Ultimate Stress

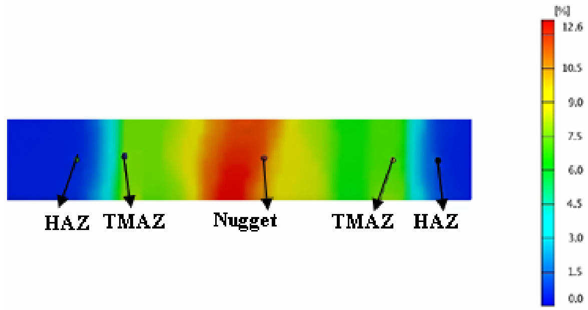


The ultimate tensile strength for different peening conditions

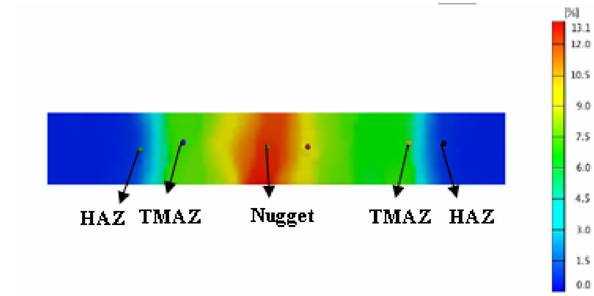


The yield stress (0.2% offset) for different peening conditions

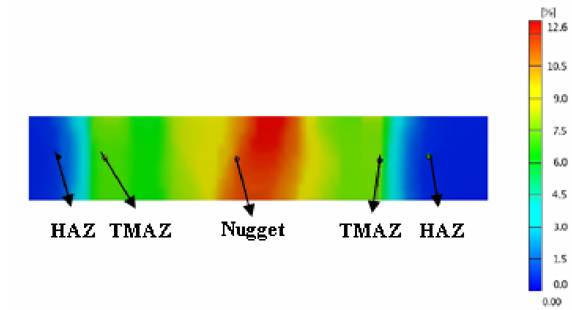
Strain Distribution Across the Weld



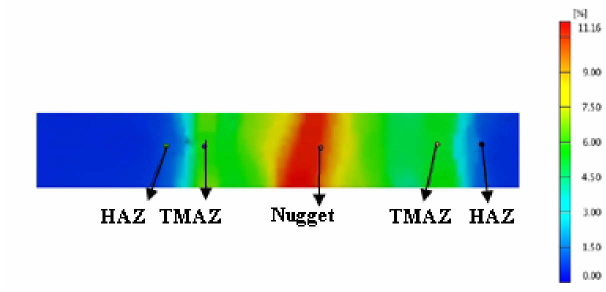
Unpeened



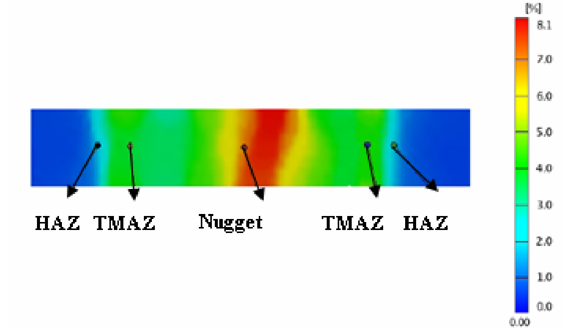
Shot Peened



Laser Peened (1 Layer)

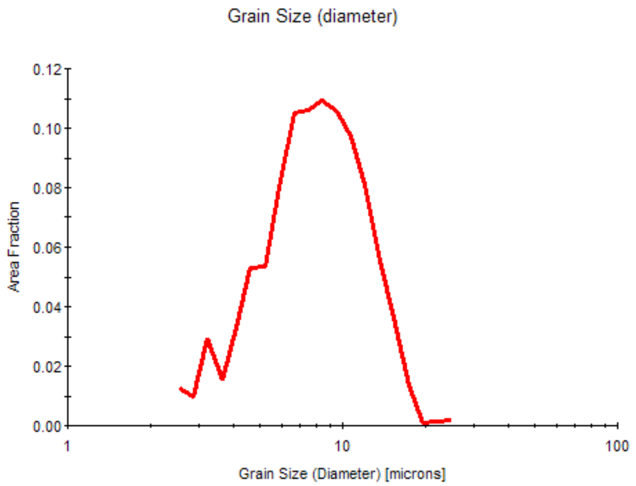


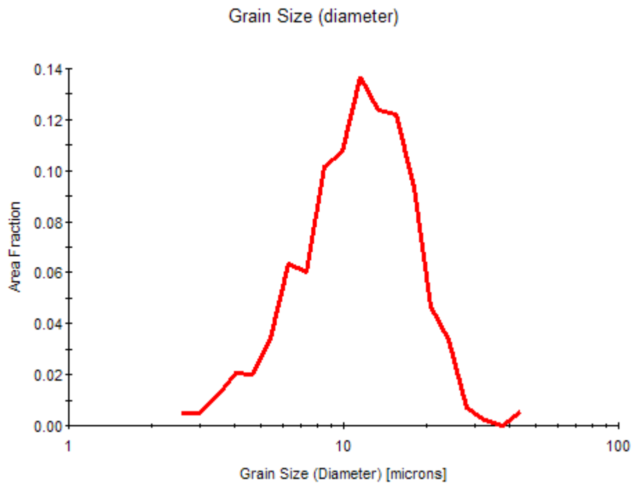
Laser Peened (3 Layers)



Laser Peened (6 Layers)

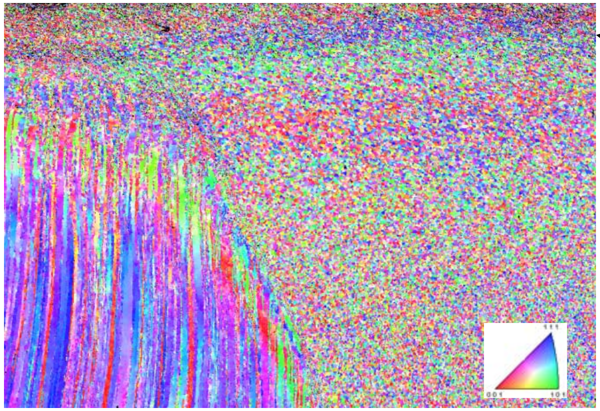
EBSD Grain Size Difference

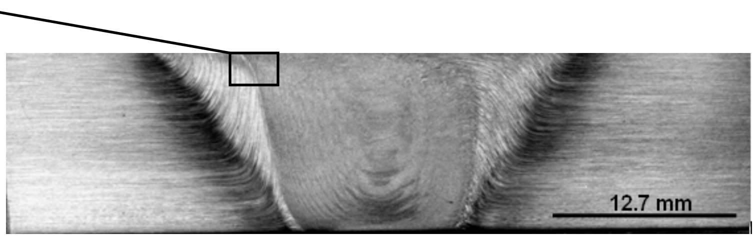




Grain size histogram for laser peened specimen

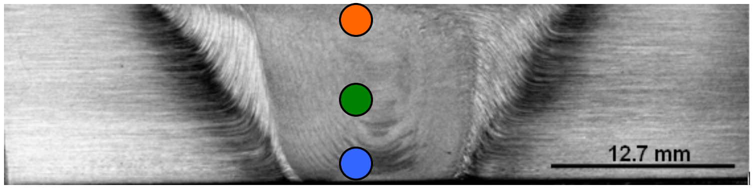
Grain size histogram for unpeened specimen





Yield Stress at Various Depths

Six layers of laser peening



Crown Side (397 MPa)

Middle Side (341 MPa)

Root Side (433 Mpa)

Yield Stress

Tensile Properties

Tensile Properties

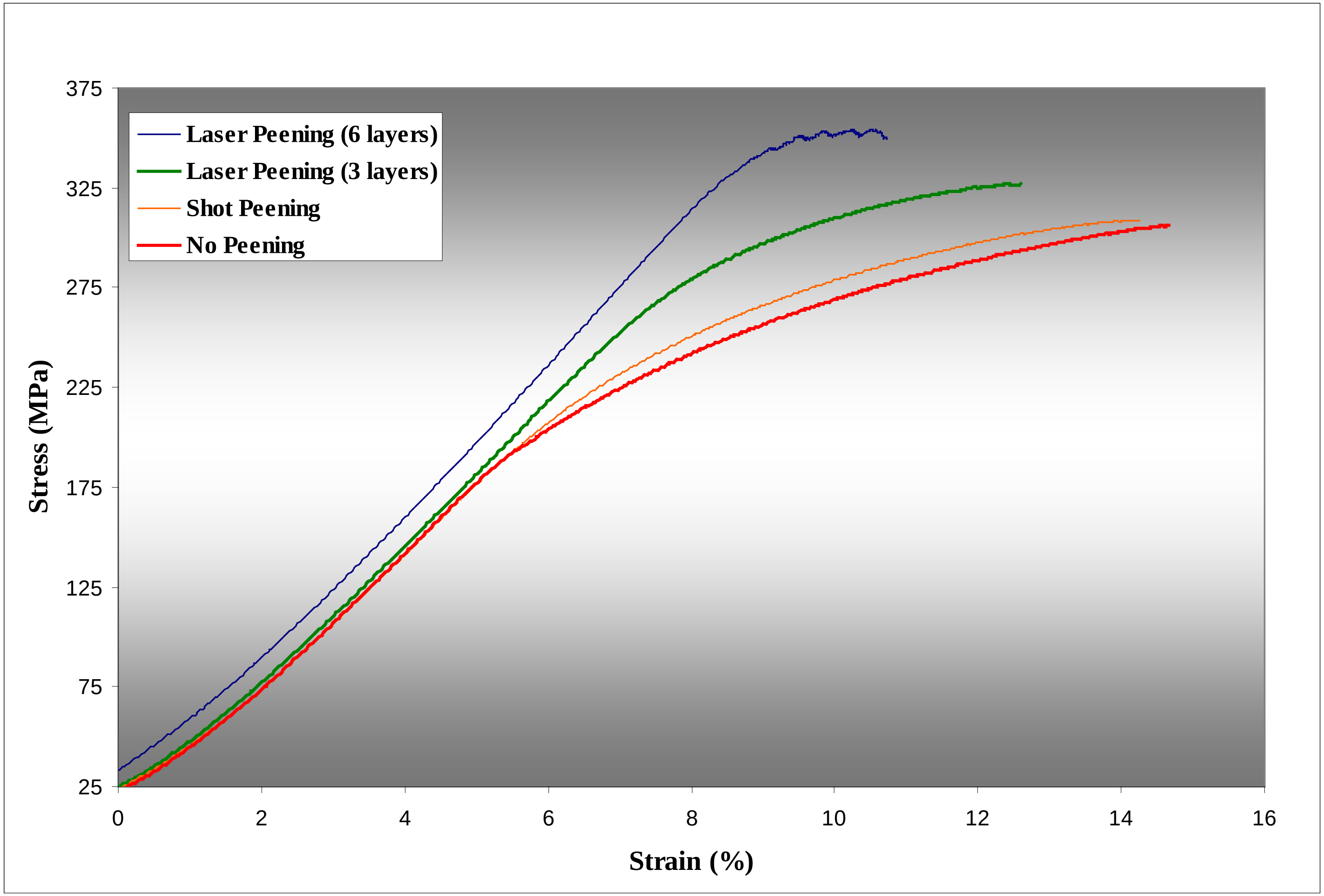
- 60% increase in the yield strength in the weld nugget in the FSW joint
- 11% increase in ultimate tensile strength in the weld nugget
- Shot peening exhibited only modest improvement in tensile properties (3%)

Improvement

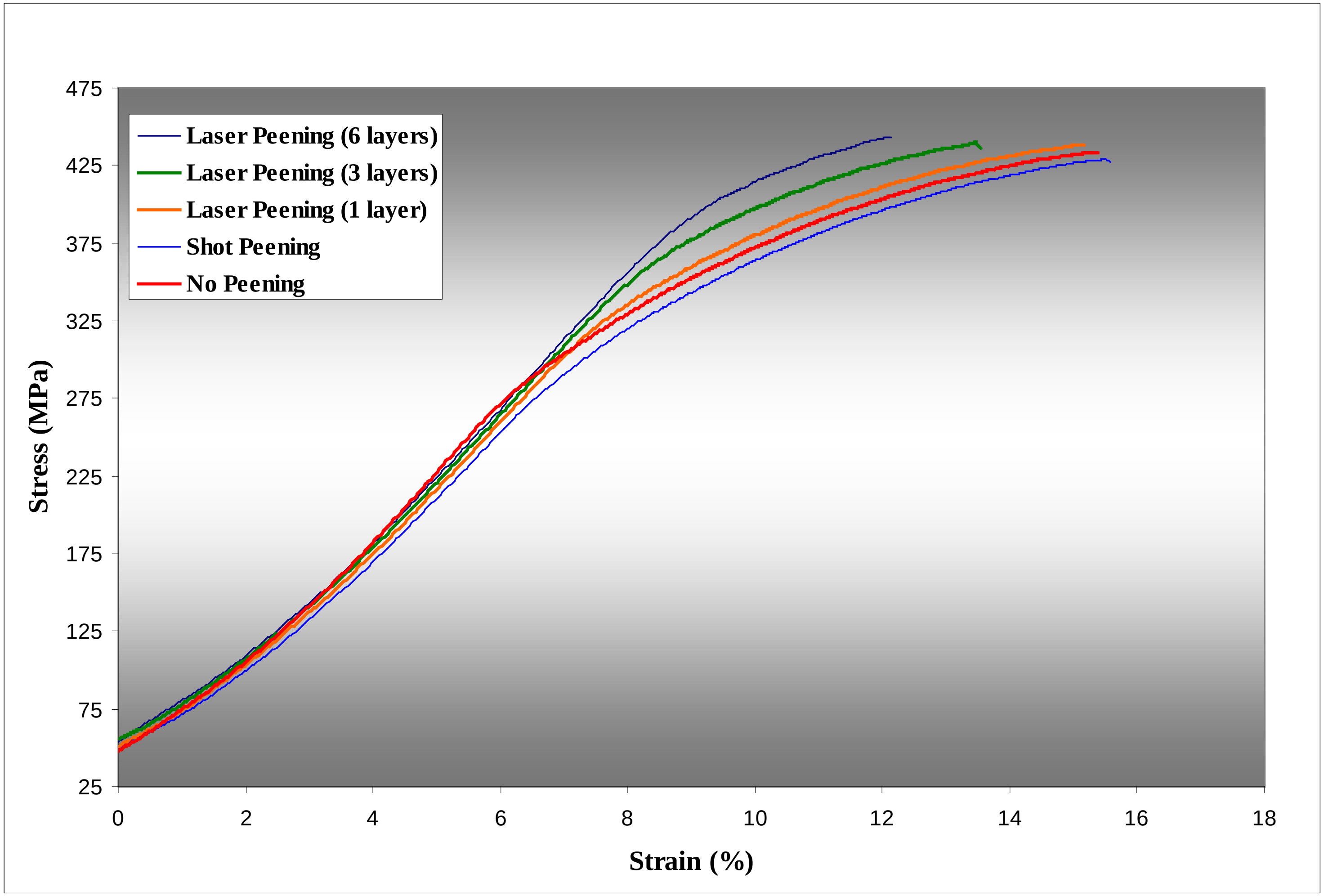
The increase in mechanical properties from the laser peening was mainly attributed to:

- High levels of compressive residual stresses introduced during the high energy peening that can reach significantly deeper than shot peening
- Increase in dislocation density from the peening

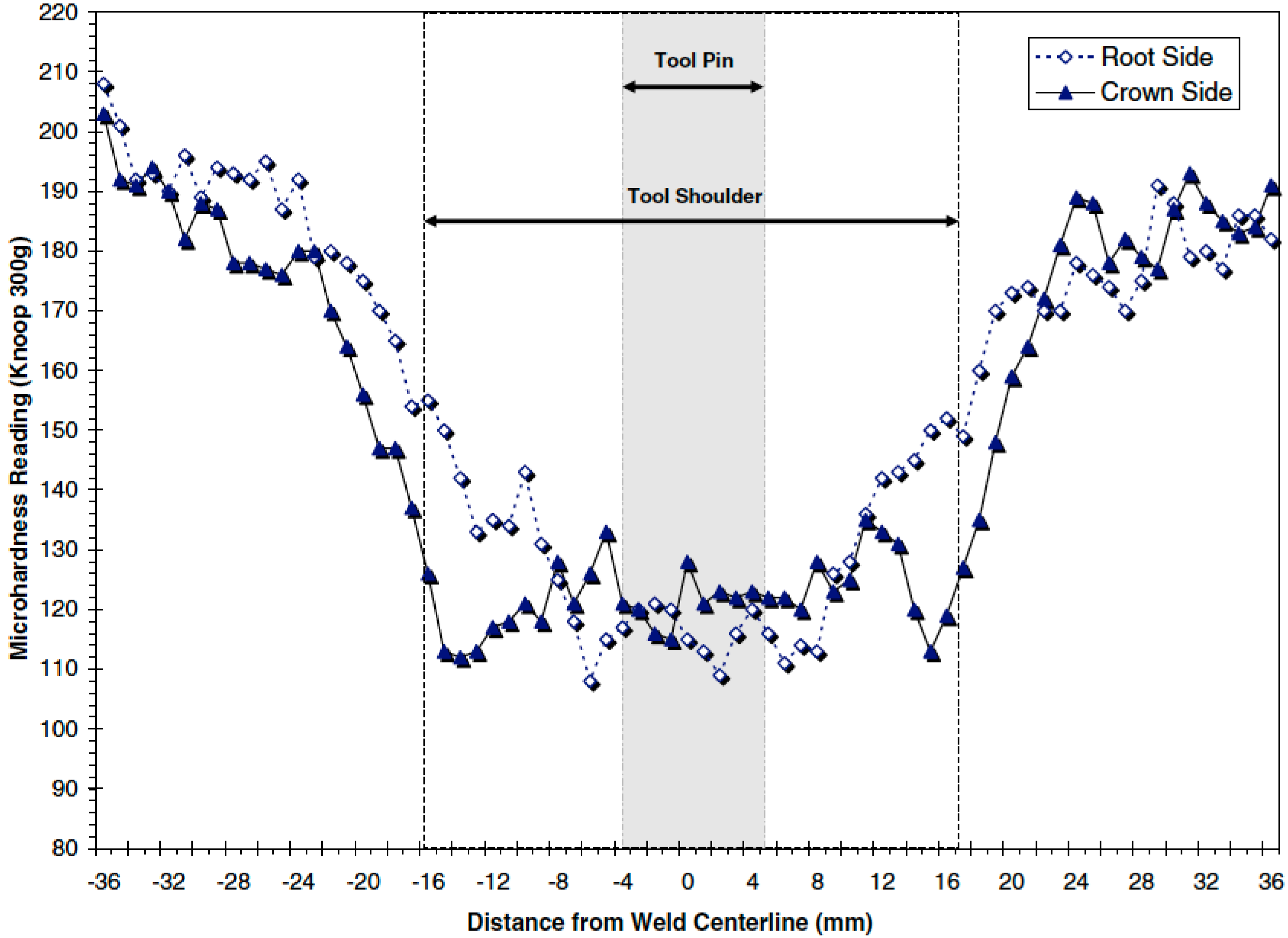
Tensile Properties at 360F



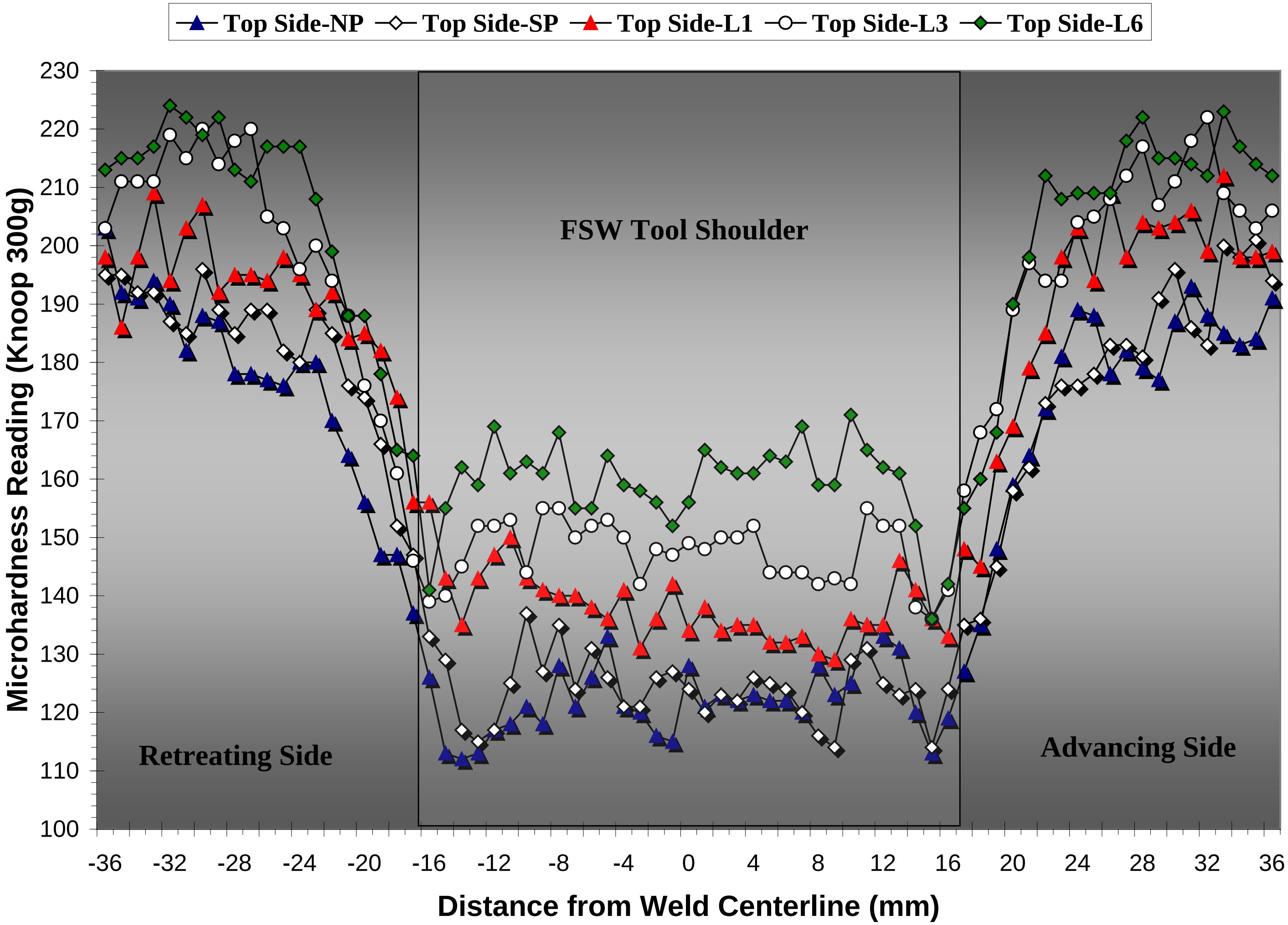
Tensile Properties at -150F



Microhardness Distribution Across Weld



Microhardness at the Top Region of the Weld



Microhardness profile across the top side of the weld for different peening methods

Microhardness

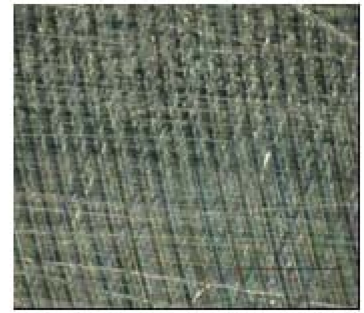
Microhardness Effects

Significant Hardness increase was achieved though Laser Peening 28% Increase on Top 21% increase on Bottom	Hardness Levels for FSW 2195 increased proportionally with number of Laser Peening layers	The polishing that takes place prior to microhardness can wipe mitigate all hardness effects associated with the Shot Peening Process

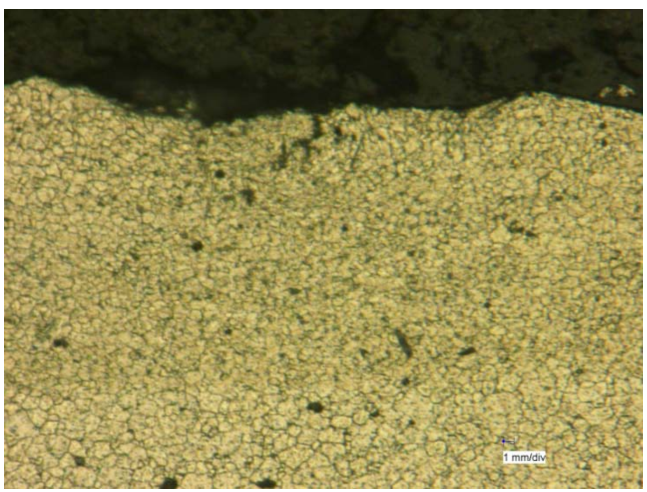
Surface Roughness

Base Material

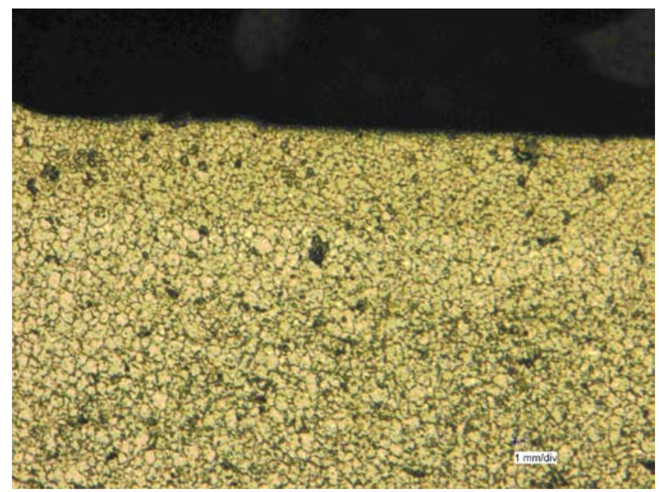
Shot Peening



Laser Peening



Shot Peening

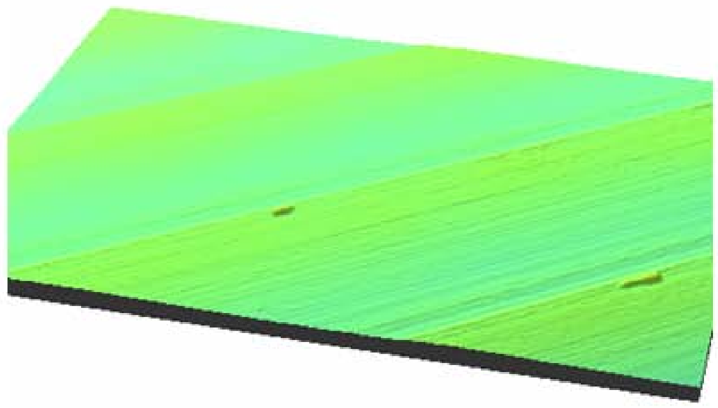


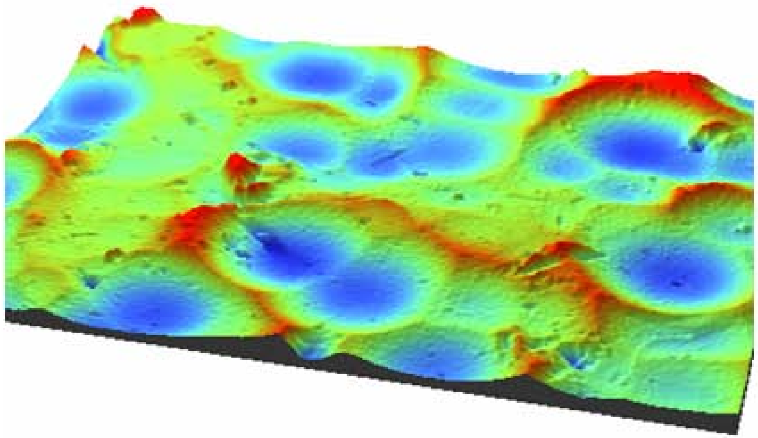
Laser peening

Surface Roughness

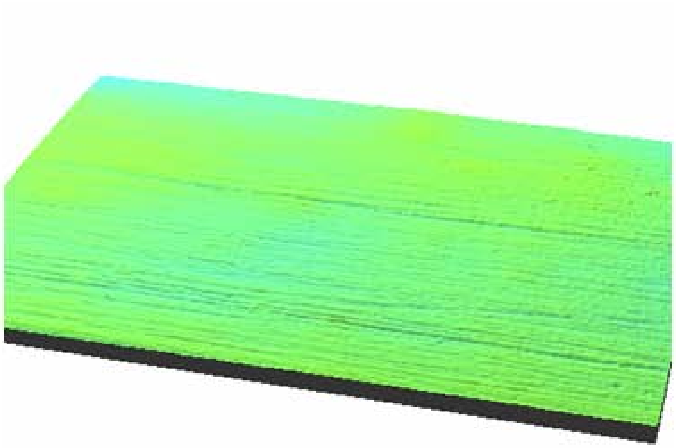
Condition	Ra	Rpk	Rvk	Nomenclature
Unpeened	1.087 µm	1.429 µm	0.93 µm	**Ra:** Roughness average **Rpk**: Maximum peak height **Rvp:** Maximum valley depth
Shot Peened	5.029 µm	5.761 µm	2.884 µm	
Laser Peened (6 layers)	1.336 µm	1.815 µm	1.328 µm	

Surface Roughness

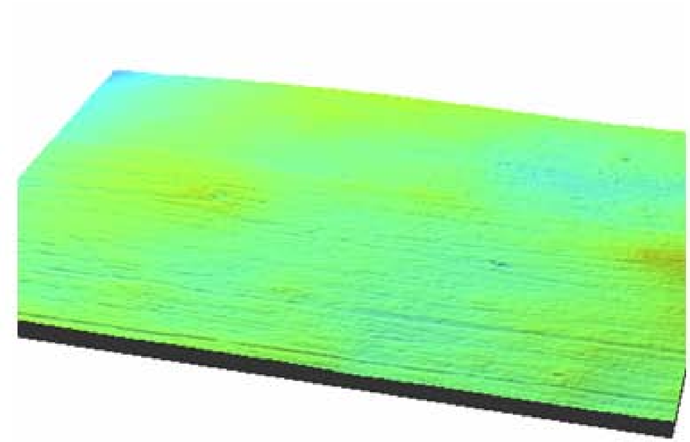

No Peening


Shot Peening

Surface Roughness

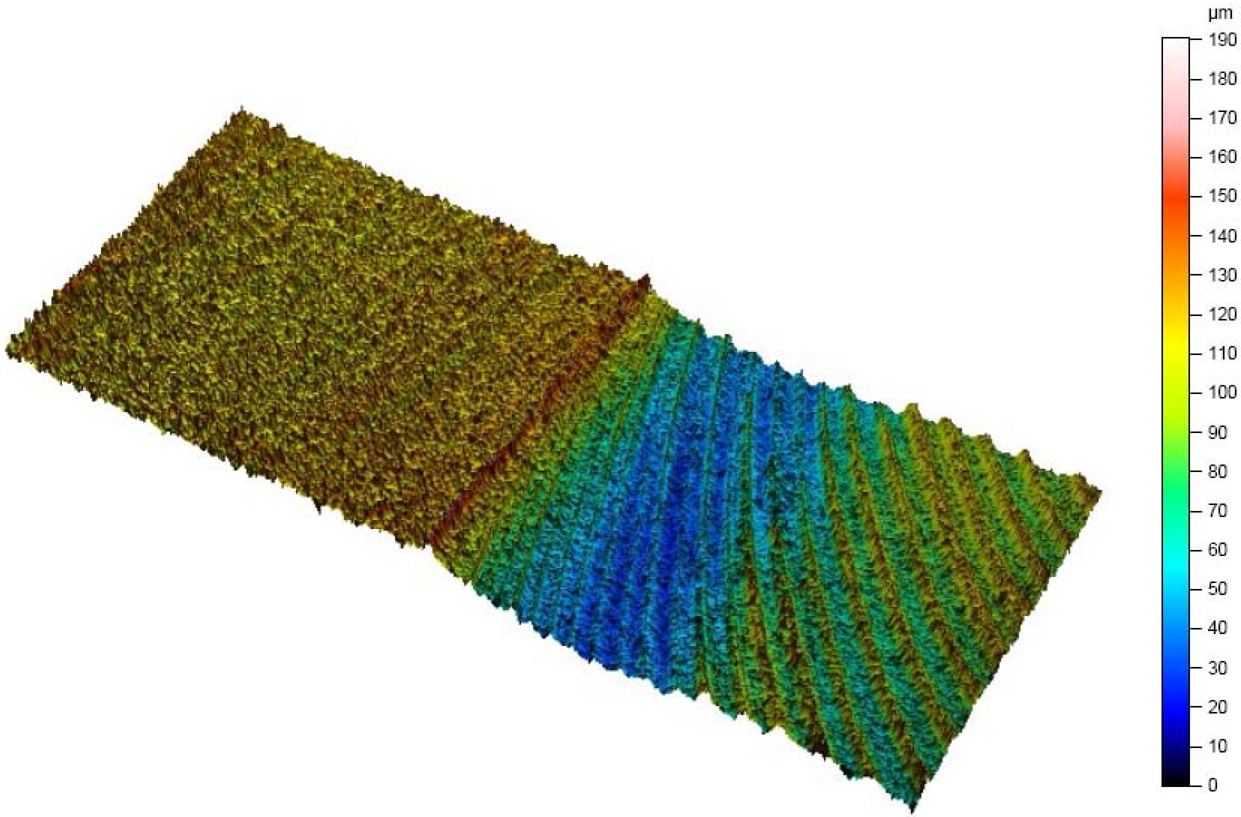


Laser peening (Three layers)



Laser Peening (Six layers)

Surface Roughness



Fatigue Crack Growth

Fatigue Crack Growth

Fatigue Testing

Room Temperature

Elevated Temperature (360F)

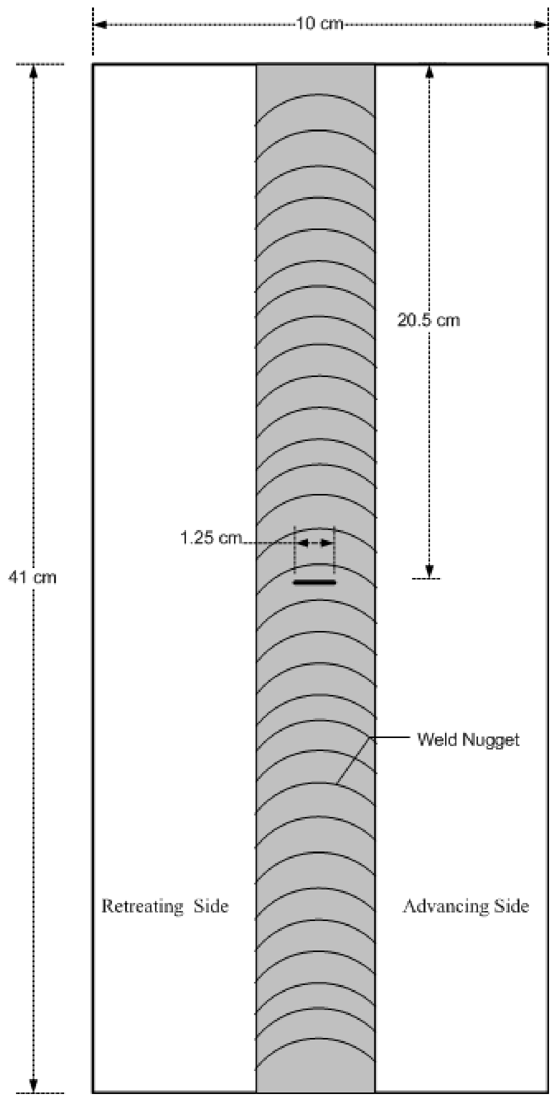
Cryogenic Temperature (-150F)

No Peening

Shot Peening

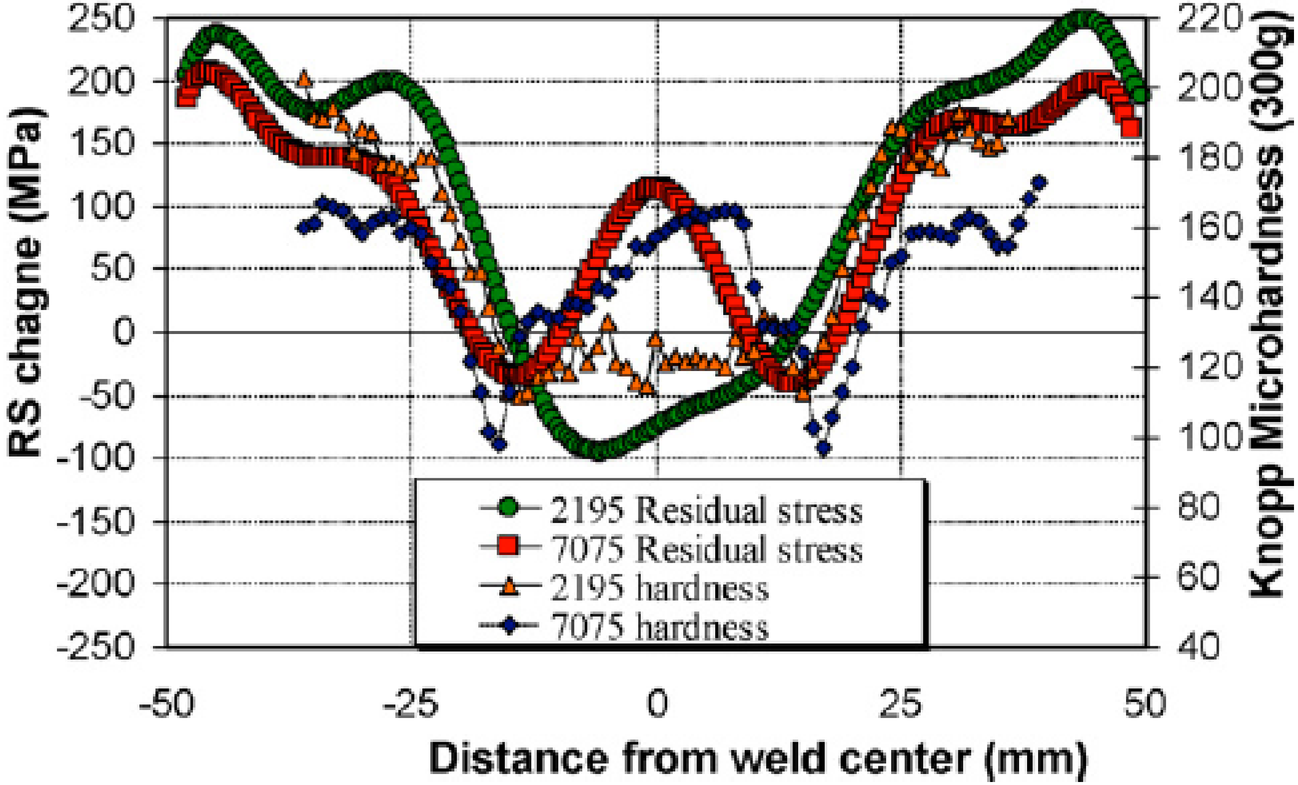
Laser Peening

Testing Samples

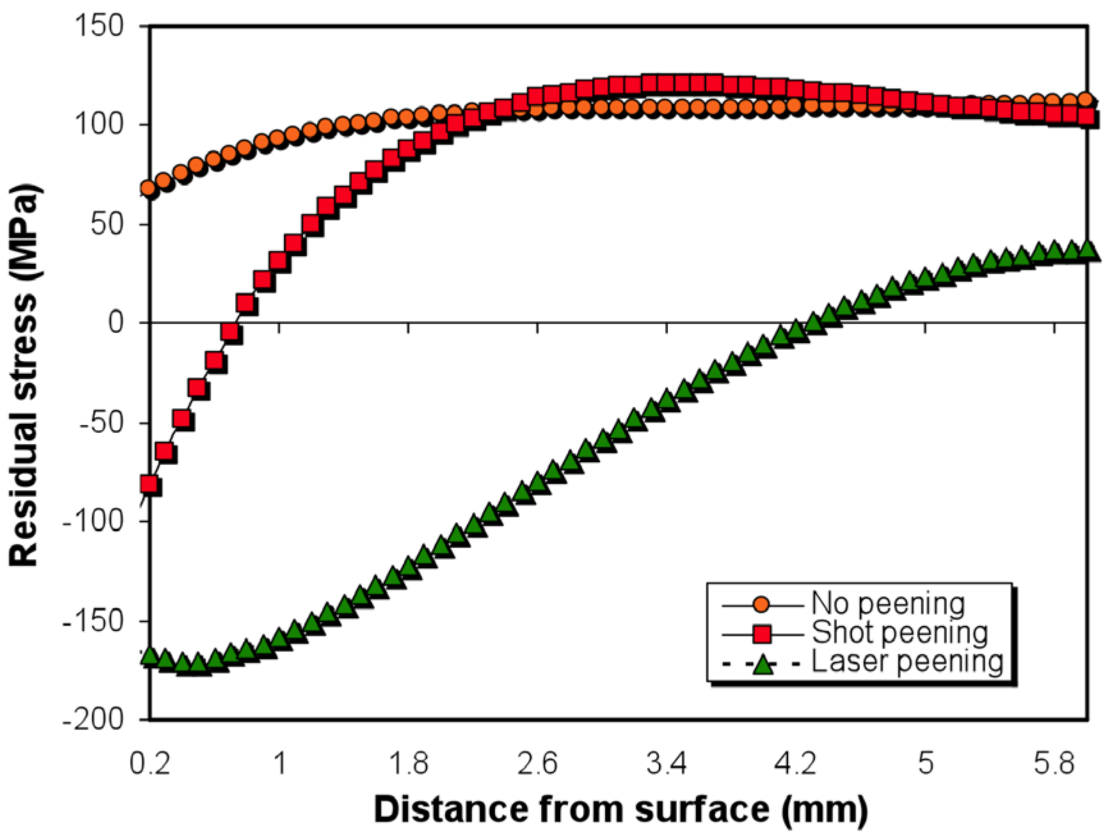


Through Thickness Cracks

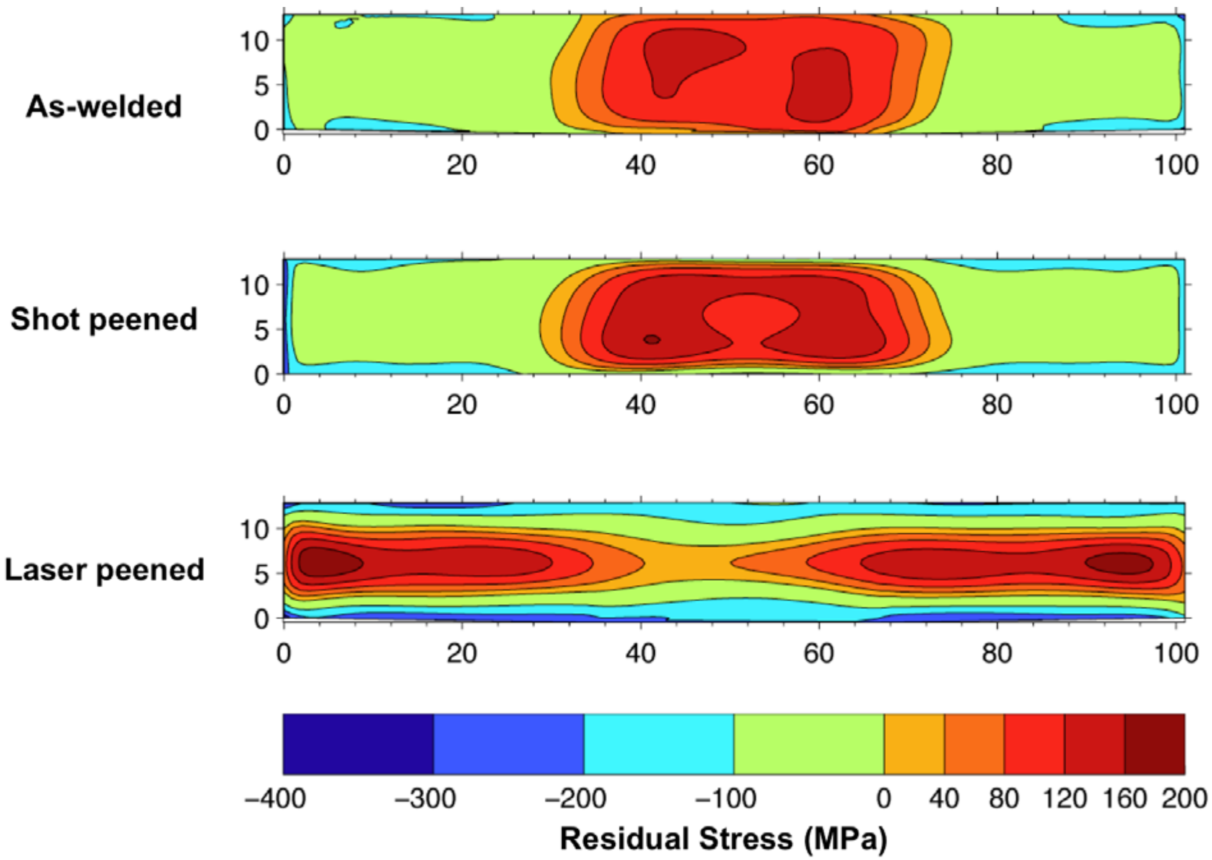
Residual Stress vs. Hardness



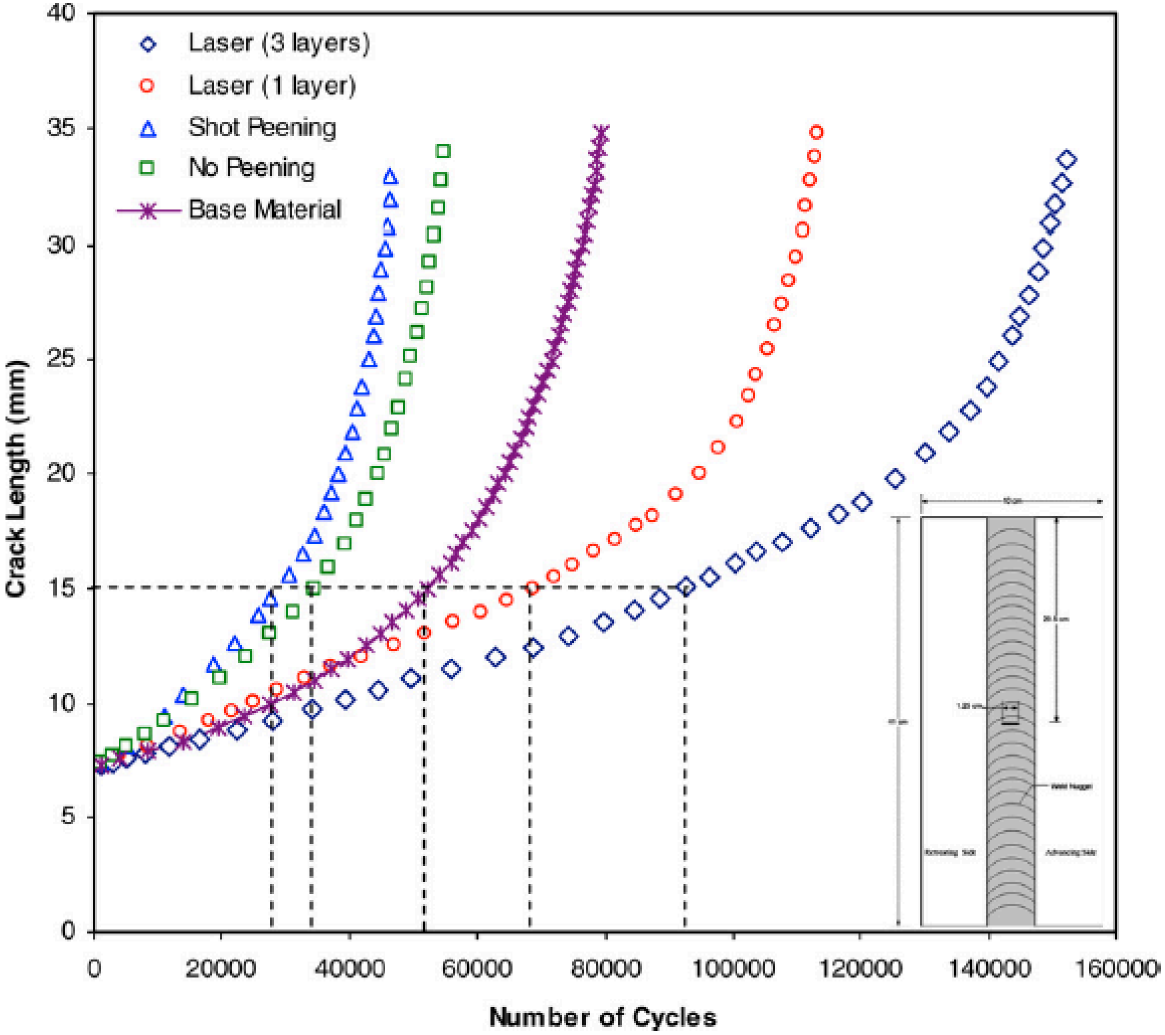
Through Thickness Residual Stress



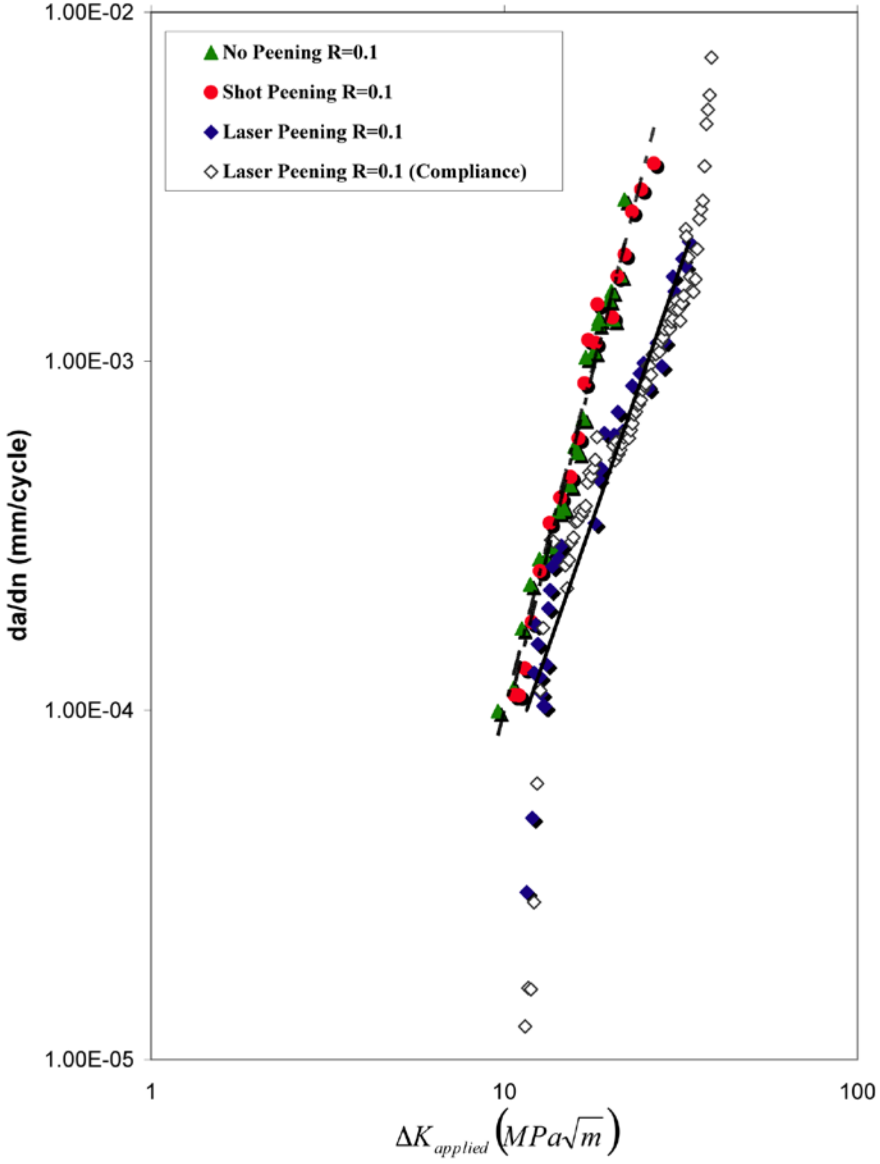
Through Thickness Residual Stress

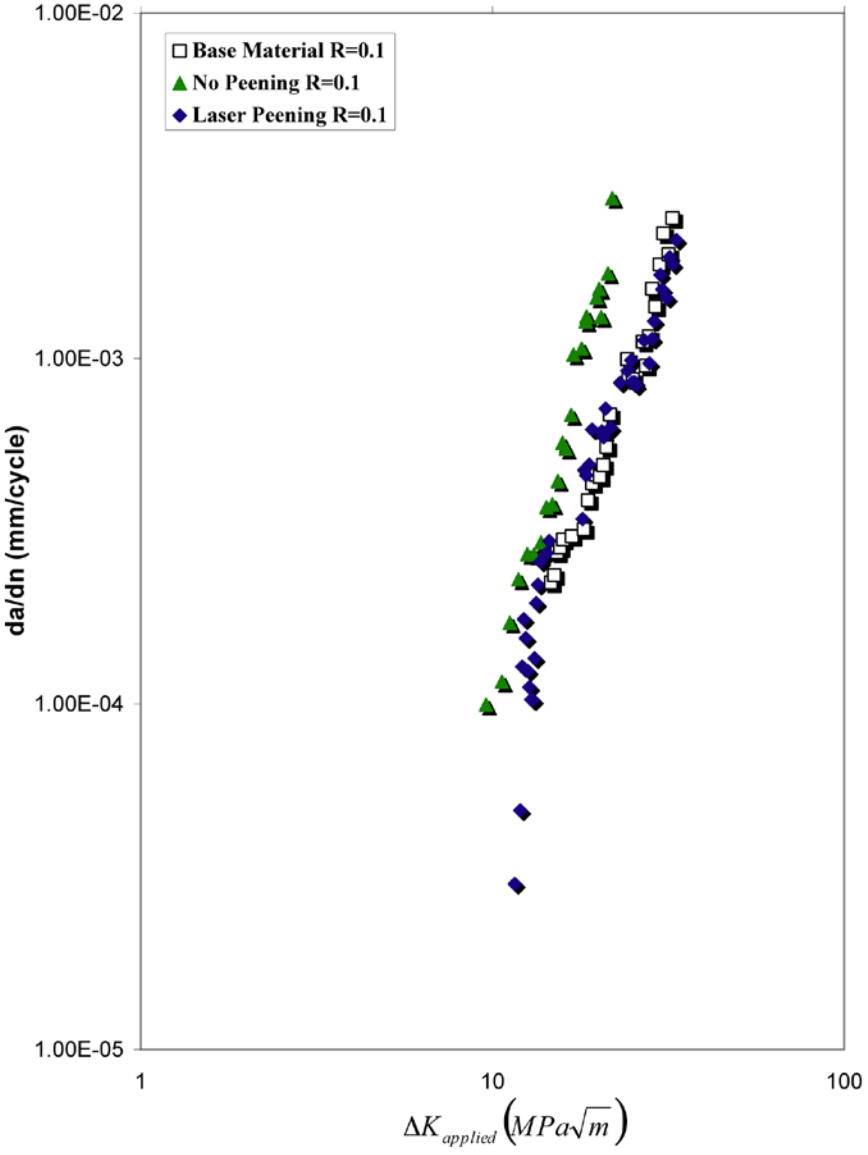


Fatigue Crack Growth Rates for 7075

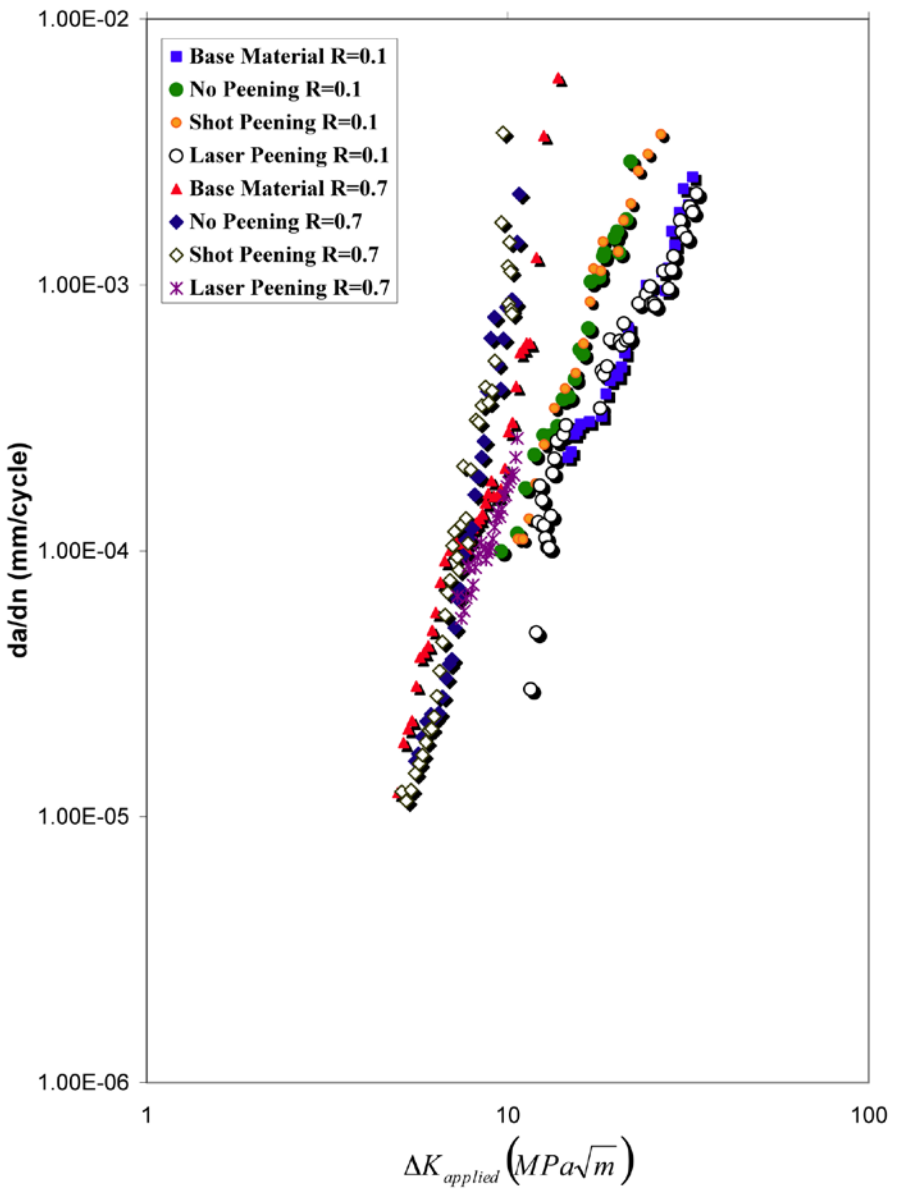


FCGR For Different Conditions for 7075

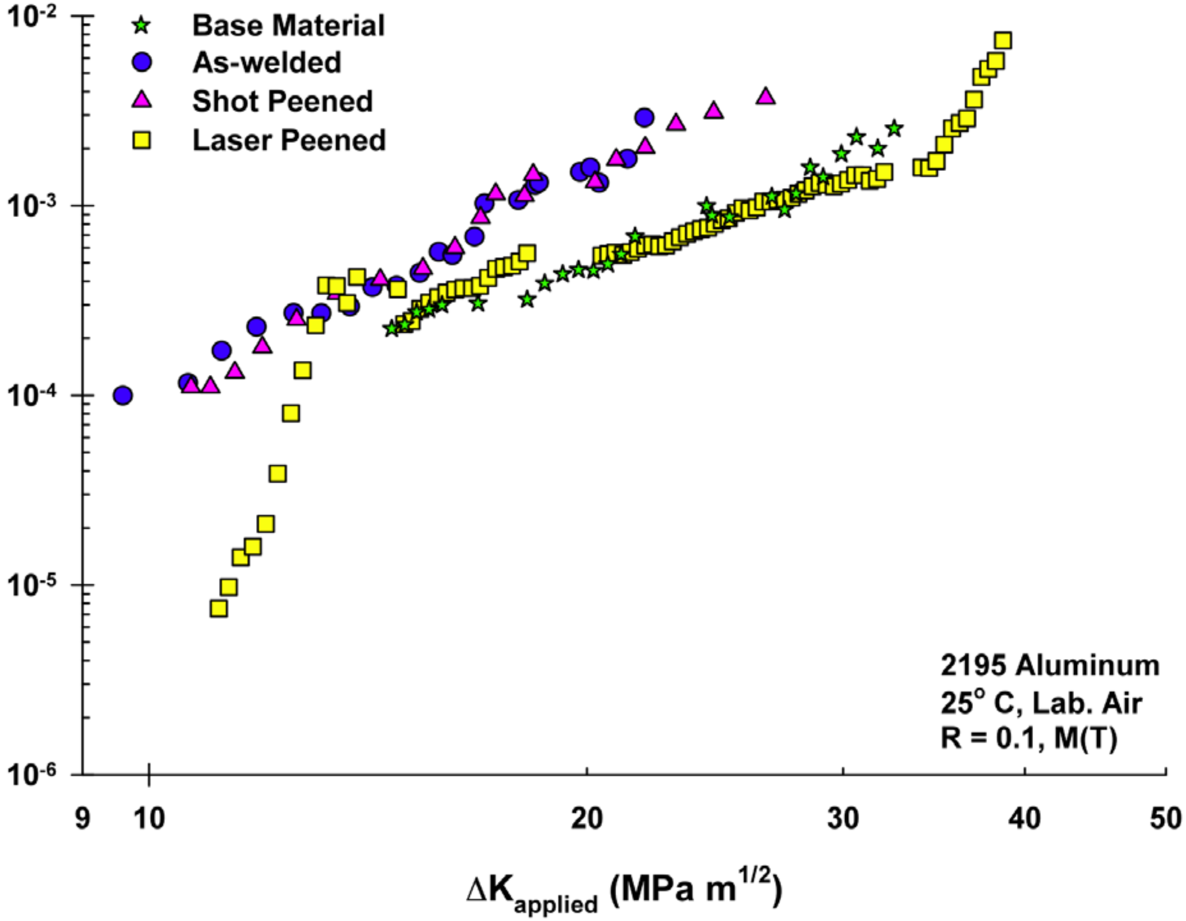




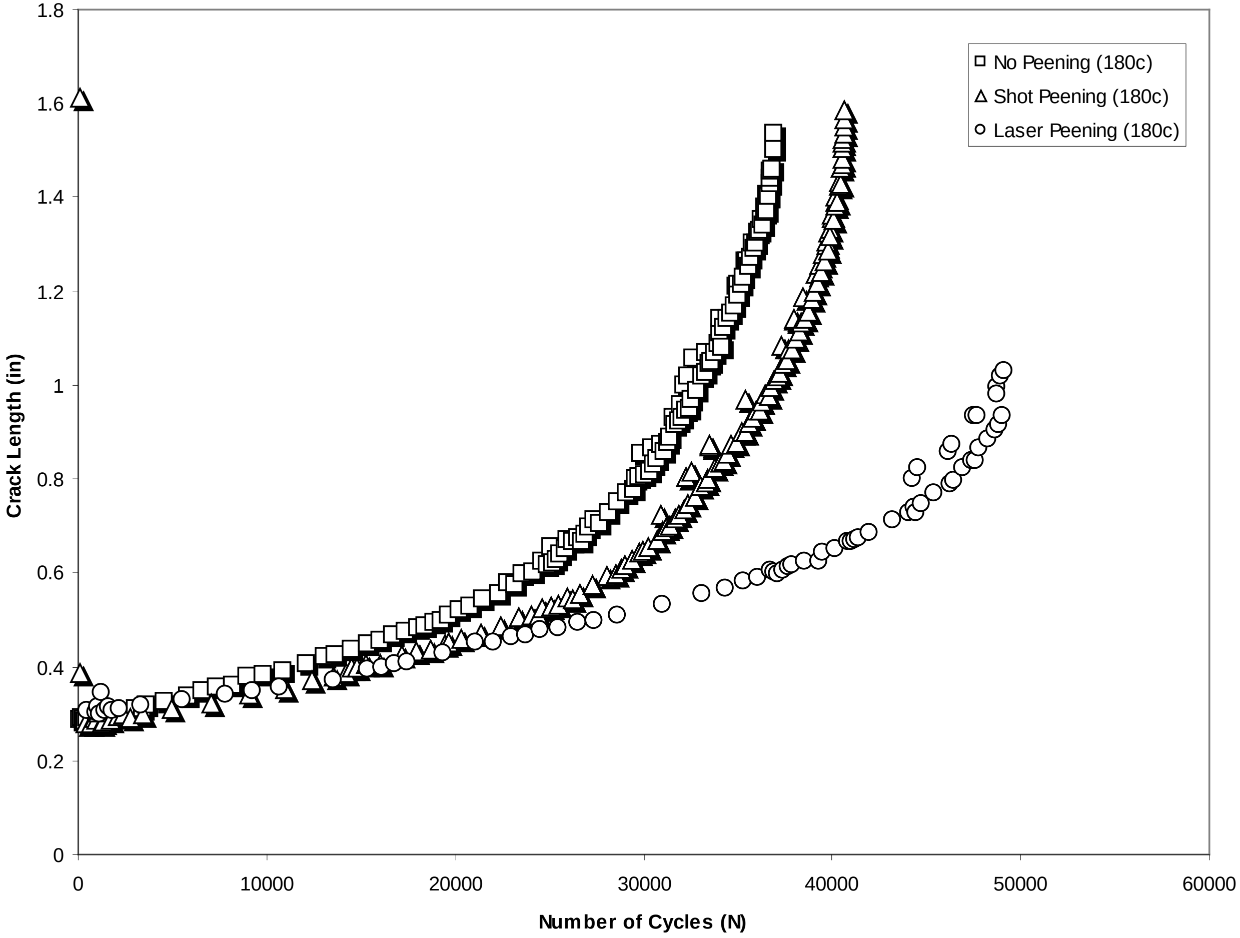
Fatigue Crack Growth Rates for 7075



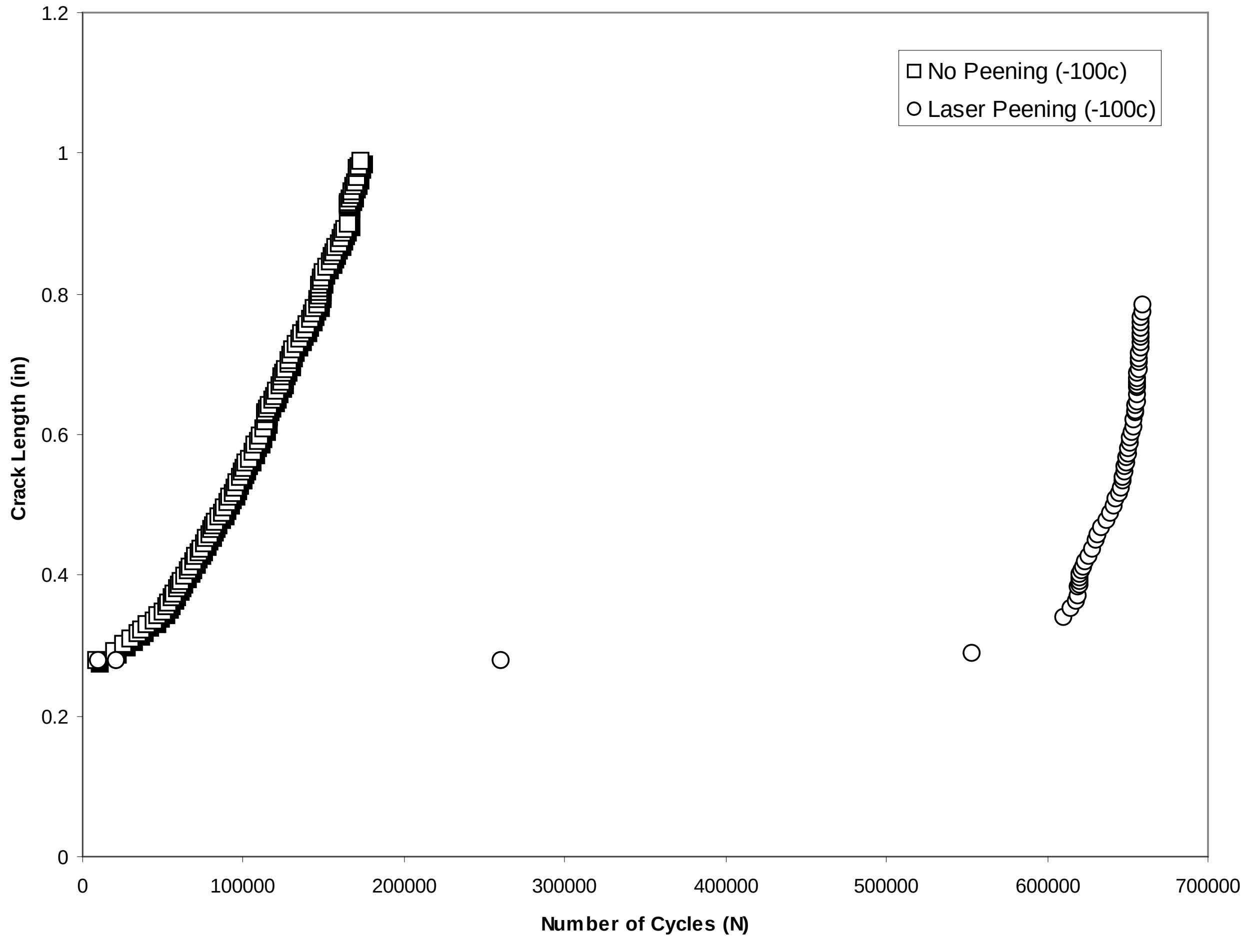
Fatigue Crack Growth Rates for 2195



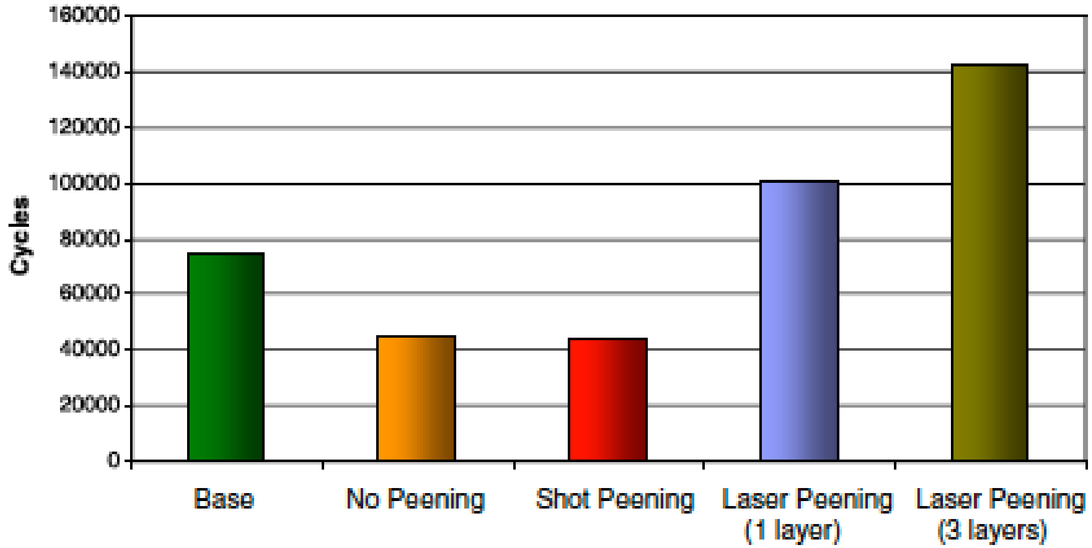
Fatigue Crack Growth Rates at 180 Degrees Celsius



Fatigue Crack Growth Rates at -100 Degrees Celsius

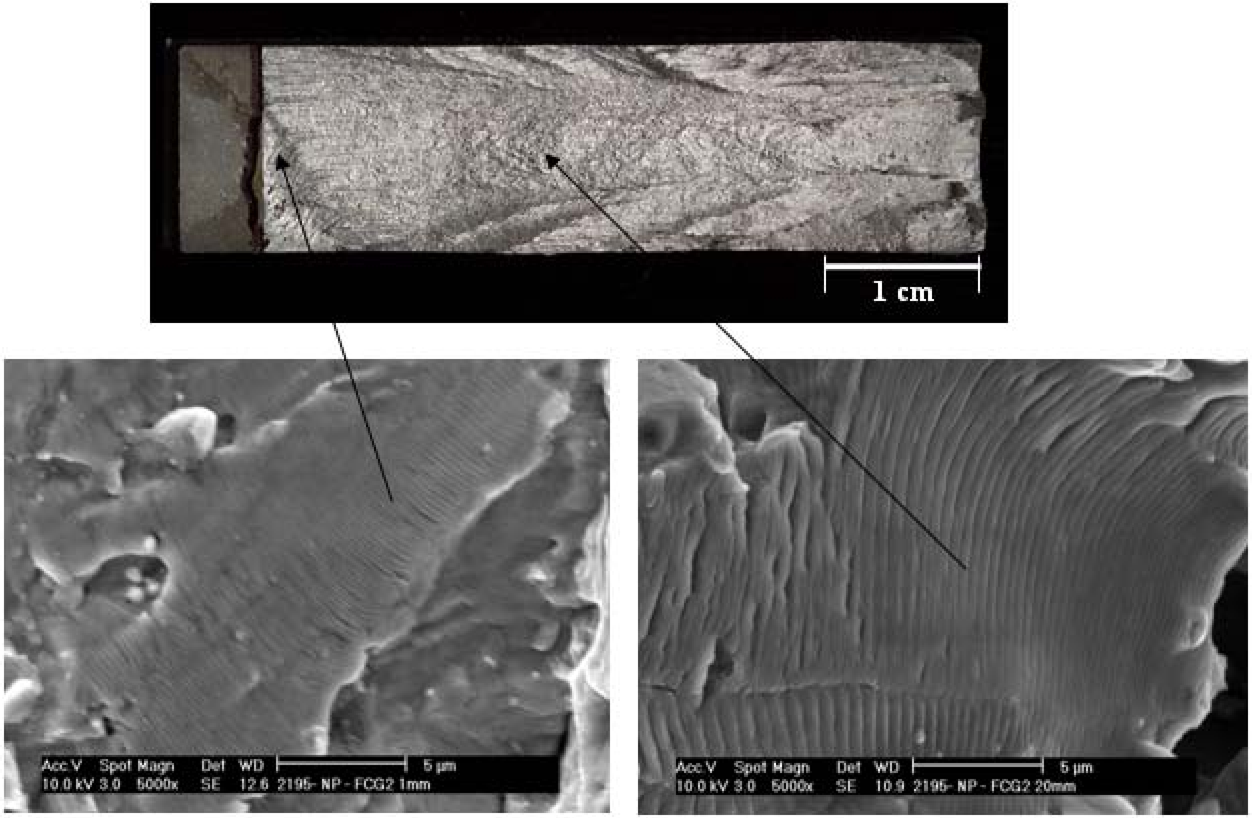


Fatigue Crack Growth Rates



Number of Cycles to grow a 25mm crack from one side of the EDM notch

Fractured Surfaces



Fractured surface and fatigue striations of an unpeened sample at R=0.1

Conclusions

Longer hardware service life

- The laser peening process can result in **Considerable Improvement** to crack initiation, propagation, and mechanical properties in FSW

Improve processed hardware safety

- By producing **Higher Failure Tolerant** hardware, & reducing risk

Lower Hardware Maintenance Cost

- **Longer** hardware service life, and **Lower** hardware down time

- ***Application of this proposed technology will result in substantial benefits and savings throughout the life of the treated components***